

1
Ag 84A6

5

THE EFFECT OF SOILS AND FERTILIZERS ON HUMAN AND ANIMAL NUTRITION

AGRICULTURE
INFORMATION
BULLETIN NO. 378



PAO JUNE 1975
CURRENT SERVICE 116

JUN 9 1975

U.S. DEPT. OF AGRICULTURE
NATL. AGRIC. LIBRARY



Agricultural Research Service and Soil Conservation Service
United States Department of Agriculture in Cooperation With
Cornell University Agricultural Experiment Station

The Effect of Soils and Fertilizers on Human and Animal Nutrition

By W. H. Allaway

Agriculture Information Bulletin No. 378

**Agricultural Research Service
and
Soil Conservation Service
UNITED STATES DEPARTMENT OF AGRICULTURE
In Cooperation With
Cornell University Agricultural Experiment Station**

Washington, D.C.

Issued March 1975

**For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402 - Price 80 cents
Stock Number 0100-03378**

Preface

This bulletin is the third in a series prepared at the U.S. Plant, Soil and Nutrition Laboratory, Ithaca, N.Y., summarizing current information on the effect of soils and fertilizers on the nutritional quality of plants. The first, Miscellaneous Publication 664, appeared in 1948, and the second, Agriculture Information Bulletin 299, was printed in 1965. New information developed by research workers at many places in the United States and in other countries has made possible the expansion and updating of the previous bulletins. Hopefully this bulletin will also require updating as research programs continue to provide a better understanding of the food chain from soil to plant to animal and man.

The author expresses his deep appreciation to his colleagues at the U.S. Plant, Soil and Nutrition Laboratory and to other research workers all over the world for the ideas and information included here.

Contents

	Page
Sources of essential nutrients for humans and animals.....	1
Food production by plants.....	3
Transfer of elements from soils to plants to animals and people.....	6
Boron.....	9
Calcium.....	10
Chlorine.....	11
Chromium.....	12
Cobalt.....	12
Copper.....	14
Fluorine.....	15
Iodine.....	16
Iron.....	17
Magnesium.....	19
Manganese.....	20
Molybdenum.....	21
Phosphorus.....	23
Potassium.....	24
Selenium.....	25
Silicon.....	28
Sodium.....	28
Sulfur.....	29
Zinc.....	30
Other elements that may be essential.....	34
Some potentially toxic elements.....	34
Nitrogen in soil and protein in crops.....	36
The nitrate problem.....	40
Soil fertility and vitamins in plants.....	42
Soil depletion and nutritional quality of plants.....	44
Organic and inorganic fertilizers in relation to nutritional quality of crops.....	46
General aspects of fertilizer use and human nutrition.....	50
Summary and looking ahead.....	52

This publication supersedes Agriculture Information Bulletin 299, "The Effect of Soils and Fertilizers on the Nutritional Quality of Plants," issued October 1965.

THE EFFECT OF SOILS AND FERTILIZERS ON HUMAN AND ANIMAL NUTRITION

By W. H. ALLAWAY, *U.S. Plant, Soil and Nutrition Laboratory, Northeastern
Region, Agricultural Research Service*

Do fertile soils always produce nutritious food and feed crops?

*Has soil depletion endangered the nutritional quality of the food
crops produced on U.S. farms?*

*Do crops produced in some places provide people and animals with
essential minerals that are not provided by crops grown in other places?*

*If a plant grows well and makes a satisfactory yield, will it always
be a satisfactory source of essential minerals for man and animals?*

People have speculated, and argued, about relationships between soils and human health for a long time. Some questions have not been answered to everyone's satisfaction, but reasonable answers to some others have emerged from the results of scientific research and from experience. These questions can be answered only in respect to specific plants, animals, and kinds of soil.

The purpose of this bulletin is to examine some of these questions in the light of current knowledge of the food chain from soils to plants to animals and man.

Sources of Essential Nutrients for Humans and Animals

A great many materials must be present in human and animal diets for a person or animal to have optimum health over a normal life-span. Included in these required materials are carbohydrates, fats, proteins—or more accurately the amino acids found in proteins—vitamins, and the essential mineral elements. Most of the mineral elements required by humans and animals move from the soil to the plant. The concentration of these elements in the plant may reflect the amount of these elements in the soil. No single food plant contains all of these required nutrients in amounts sufficient to sustain human health. The need to fortify foods with salt to supply the nutrient elements sodium and chlorine was recognized centuries ago.

A striking example of a relationship between soil and human health involves the incidence of goiter and cretinism in people. Less than 100 years ago goiter in adults and cretinism in children were prevalent in many areas where the soils and the plants that grow on them were low in iodine. The water in these regions was also low in iodine. The

use of iodized salt has provided iodine in the diets of people in many of these areas, and the incidence of goiter and cretinism has declined.

In considering the relationship between soil and human nutrition, it is necessary to distinguish between hunger due to lack of food and deficiency of specific nutrients due to poor quality food. Where low crop yields are due to infertile soil or inadequate soil-management practices and the population is dense, hunger and famine have been common throughout history. The same soils or the same system of soil management might have provided an adequate and nutritious food supply for a smaller population. Deficiencies in the nutritional quality of the crops produced in famine-stricken countries may have contributed to these disasters, but these defects in quality were not apparent because of the overriding impact of the total food shortage.

In most countries, especially in the industrialized areas, the daily diet of people comes from many different plants grown on many different kinds of soil. Food products of animal origin may be major sources of such essentials as iron, protein, and phosphorus in human diets. A resident of the Northeastern United States during a typical day may obtain vitamin C contained in citrus fruit from Florida, calcium from Wisconsin cheese, protein from beef produced in Iowa or from bread baked from Kansas wheat, vitamin A from California lettuce, and so on. Each of these foods also contains other nutrients that are essential for people.

The nutritional quality of a plant cannot be considered without considering the other components, including the supplements, that make up the diet. Rice is a major source of calories in the diets of people throughout the world, but a diet consisting solely of rice would not sustain life. Potatoes may be low in protein and yet be an excellent source of carbohydrates and some of the vitamins and minerals.

It is difficult to determine the effect of any one soil or plant on human health because of the numerous and varied sources of dietary essentials. The relationship between iodine and goiter was detected because iodine deficiency occurred over broad areas of the world and at a time when long-distance shipments of foods were less common. Because the effects of soil on human health have been so difficult to study, scientists have generally directed their efforts to a different approach. They attempt to identify the various essential nutrients, to determine which foods contain these nutrients, and to understand how the concentration of these nutrients is controlled by the fertility of the soil on which food or feed plants are grown. Much useful information has resulted from this research.

For example, there is evidence that deficiencies of iron, zinc, magnesium, chromium, and other elements may occur among people in the United States. Although these elements are taken up from the soil by food crops as the first step in their movement along the food chain, no clear relationship between the levels of these minerals in soils and their

deficiency or adequacy in human diets has been established. Research on these problems is continuing.

In contrast to the diets of people, the diets of farm animals frequently originate from just a few species of plants, and these are often grown on one or two similar kinds of soil. There are numerous instances where the health of farm livestock has been affected by the quality of the soil where the feed and forage for these animals are produced. These include phosphorus deficiency in animals, cobalt deficiency in cattle and sheep, deficiency of magnesium, and toxicity from molybdenum in pastures. Some areas produce plants containing toxic levels of selenium, and other areas produce crops containing too little selenium for animals. The research work that has led to the understanding and correction of these problems has had a major impact on increasing animal production in many parts of the world. Indirectly this research has improved the nutritional status of people, because animal products can now be produced on soils that would not support animals until the deficiencies were corrected.

Food Production by Plants

In the ecosystems that cover the globe, green plants capture energy from the Sun and store this energy in organic compounds synthesized within the plant. These organic compounds then provide a usable source of energy for the man or animal that eats the plant. The carbon atoms that make up the framework of these organic compounds enter the plant from the air as carbon dioxide gas absorbed by the leaves. Plants take up oxygen from the air for some of their metabolic processes and release oxygen back to the air from other metabolic processes. The formation of organic compounds from inorganic materials is the primary role of green plants in the food chain.

In order for green plants to grow and form organic compounds, they must take up water and several essential elements from the soil. These elements include nitrogen, phosphorus, sulfur, potassium, magnesium, calcium, iron, zinc, copper, manganese, boron, chlorine, sodium, cobalt, silicon, and molybdenum. Not all plants require all these elements.

Although it is customary to speak of essential elements in discussing plant and animal nutrition, these elements are rarely present as the pure elemental form in nature. They are nearly always combined with other elements into chemical compounds. When some of these compounds dissolve in water, they form electrically charged particles called ions. Phosphorus as the uncombined element never exists in nature because it is always linked to oxygen. In solutions it exists as negatively charged phosphate ions, PO_4 . As phosphate ions and compounds it moves through the food chain from soils through plants to animals, performing many essential functions. The accumulation of essential elements from the soil by growing plants is primarily a process of

movement of ions containing the essential elements from the soil water into the plant roots.

The movement of ions of the essential elements from the soil solution into the plant root and then on to the top is a very selective process. Some required elements move through this system very rapidly and

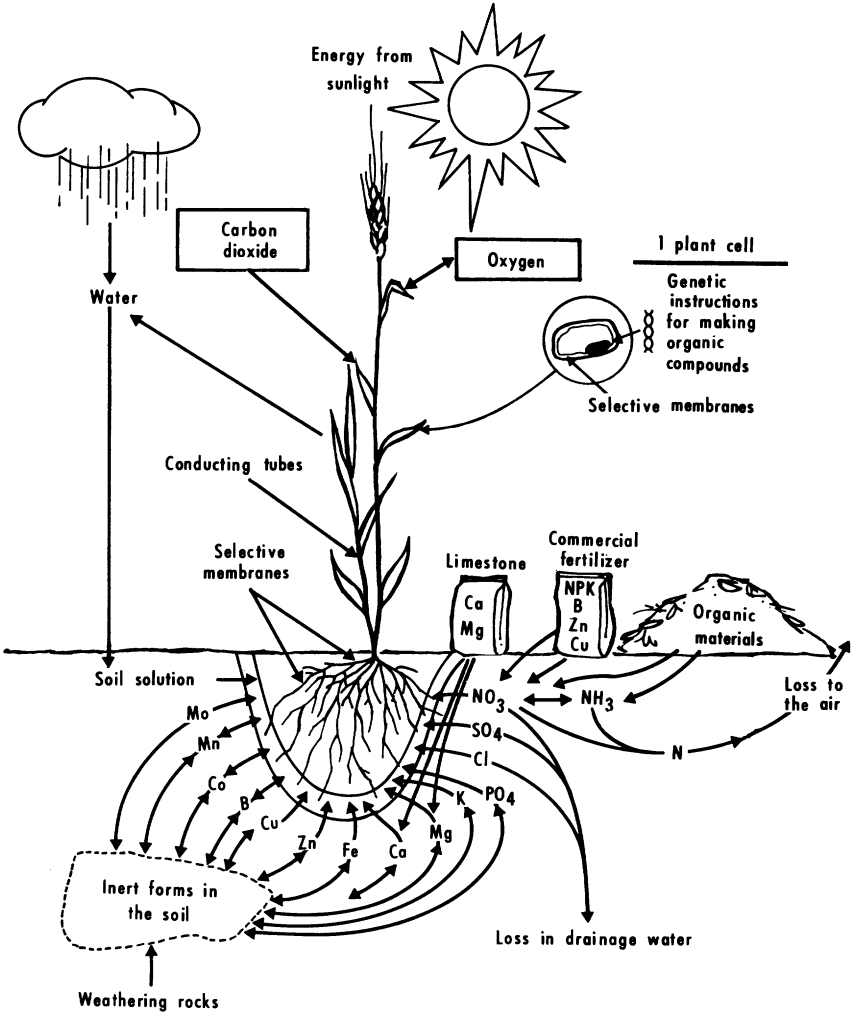


FIGURE 1.—The composition of plants is controlled by soil, genetic, and environmental factors. Mineral nutrient elements from weathering rocks, fertilizers, and organic materials are dissolved in the soil solution or held by the solid phase of the soil. From the soil solution they pass through selective membranes in the roots and move up to the top of the plant. In the green parts of the plant, energy from the Sun and carbon dioxide from the air are used to form many different organic compounds. All these processes operate according to a set of instructions determined by the genetic inheritance of the plant.

some very slowly. Other elements may be excluded from the roots of certain plants, even though they are present in the soil solution. The concentration of elements in the top of a plant is a reflection of the plant's inherited selectivity operating on the supply of soluble minerals in the soil.

Within the plant the essential elements participate in many processes of life and growth. These processes include the synthesis of proteins, transport of sugars, and formation of vitamins. Exactly how these elements function in the various life processes is generally not well understood, but it is known that the rate of accumulation of these elements from the soil is one of the factors controlling plant growth.

Another, and perhaps the most important, factor is the inherited set of directions contained in material called deoxyribonucleic acid in the nucleus of each cell. This deoxyribonucleic acid makes ribonucleic acid according to a pattern termed the genetic code. The ribonucleic acid then directs the synthesis of proteins, and many of these proteins act as enzymes to direct the metabolic processes that take place in the plant. Some of these enzymes in turn require one of the mineral nutrient elements as an aid, or cofactor, in order to do their work.

So the inherited set of directions determines whether or not a plant will form high or low levels of specific proteins, or carbohydrates, vitamins, and so forth. The accumulation of essential elements from the soil gives the plant a chance to operate according to its inherited directions, but differences in rates and extent of accumulation of these elements cannot change the directions themselves. In addition, the inherited directions are responsible for the selectivity of the accumulation process. For example, alfalfa always contains more calcium than corn even though they grow side by side, because the genetic instructions carried by alfalfa plants call for the accumulation of more calcium than do the instructions carried by corn plants.

Environmental factors, including the amount of sunlight, the temperature of the air and of the soil, the humidity of the air, and the moisture content of the soil, may also have an important impact on the concentration of essential nutrients in a plant. The amount of vitamin C in a ripening tomato is primarily controlled by the amount of sunlight that strikes the tomato. During cool, cloudy weather some grasses may accumulate high levels of nitrate. The effects of environment on plant composition may be so pronounced that certain nutritional diseases of animals occur much more frequently in some years than in others, even on the same pastures.

So, the concentration in plants of the different nutrients required by man and animals is controlled by several processes that depend on the fertility of the soil, the genetics of the plant, and the environment within which it grows. Any one of these factors may affect the level of different essential nutrients or of toxic substances in food and feed plants.

Transfer of Elements From Soils to Plants to Animals and People

Animals respond in improved health and growth to 20 different mineral elements. These include calcium, chlorine, chromium, cobalt, copper, fluorine, iodine, iron, magnesium, manganese, molybdenum, nickel, phosphorus, potassium, selenium, silicon, sodium, tin, vanadium, and zinc. These are in addition to the nitrogen and sulfur, which are required in essential amino acids, and the carbon, hydrogen, and oxygen, which come from air and water.

Deficiencies of calcium, magnesium, iron, selenium, iodine, cobalt, copper, phosphorus, and zinc have at times been responsible for nutritional diseases among farm animals. The effects of deficiency of some of the other elements listed here have been noted only when laboratory animals, such as rats or mice, have been fed highly purified diets and kept in isolators where dust and other possible contamination are rigidly excluded. Not all the elements listed here have met all the usual criteria to be classed as essential elements for animals.

Research on nutritional requirements of animals is very active and the mineral element nutritional status of people is a problem of rising interest in medical research clinics. As knowledge in this area increases, additional elements will likely be added to those considered here to be essential for animals and man. Improvements in nutrition may correct human or animal health problems that are not now understood.

A comparison of the elements that may be needed in animal nutrition with those required by plants, as listed previously, shows that many elements are needed by both. This is partially expected in that the pressures of evolutionary development might eliminate animal species that require substantial amounts of an element that was not a normal constituent of plants. And yet there are exceptions. Plants require boron, but this element has not as yet been found to be essential to animals. Animals require selenium, chromium, and iodine, and growth responses to such elements as tin and nickel have been observed under some conditions; yet these elements have not been found to be required by plants. However, many plants do contain at least small amounts of these elements.

Even though many of the same elements are required by both plants and animals, the concentration of an element needed in plant tissue for normal growth of the plant may be either higher or lower than the concentration of this element that is desirable in animal diets. For example, plants nearly always contain more potassium and less sodium than animal dietary requirements. Some plants may grow normally and make optimum yields, even though the level of molybdenum or selenium in the plant tissue is sufficiently high to make these plants toxic to animals. There is little justification for the generalization that

any plant that grows normally and makes a high yield will automatically be a good source of nutrients for the animal that eats this plant.

Sometimes adding an element that is essential for animals to the soil where food crops are produced will help to meet the animal requirements for this element. With other essential elements, other soils, or other crops, adding to the soil an element needed by animals is ineffective in meeting animal requirements for this element. The question "Do fertile soils always produce nutritious food and feed crops?" can only be answered by specifying a particular soil and its management, a specific required nutrient, and a specific food crop fed as part of a defined diet to a specific kind of animal.

The land surface of the earth is covered with many kinds of soil. Some of them naturally contain an abundant supply of many of the elements needed by both plants and animals; other soils may contain very limited supplies of these elements. Some soils may have an abundant supply of certain required elements and yet be deficient in others. For example, soils are often found to contain an abundance of available calcium and yet have very little available zinc.

Often the total amount of any particular element found in the soil is not a good indicator of the amount of this element that can be taken up by plant roots. Different soils vary greatly in the extent to which the nutrients contained in them will become available to plants. Generally the minerals in the soil must weather to convert the nutrient elements to forms that will dissolve in water before these elements are taken up by plant roots. Iron deficiency in plants can sometimes be found in soils that are rich in iron, but where the iron is of such low solubility that plants cannot take it up. When essential nutrients are added as soluble fertilizers, they may revert to insoluble and unavailable forms very rapidly in some soils, whereas these same fertilizer nutrients may remain soluble and available to plants in other soils.

Differences between plant species in their tendency to accumulate different elements are often important in determining the mineral status of animals that eat these plants. In many places in the United States such forage legumes as alfalfa and clovers contain adequate levels of cobalt for cattle and sheep, whereas grass species in the same fields or pastures do not contain enough cobalt to meet the requirements of these animals. In some places in the Great Plains States some native species of vetch accumulate toxic levels of selenium, yet farm crops and range grasses growing in the same place will contain substantially lower, and generally nontoxic, levels of this element.

When an animal or a person eats a plant, some of its essential elements pass through the walls of the gut into the bloodstream and then to various parts of the body, where they are needed for life processes. The elements in the food are generally not completely absorbed. Often over 80 percent of the iron contained in the food goes through the

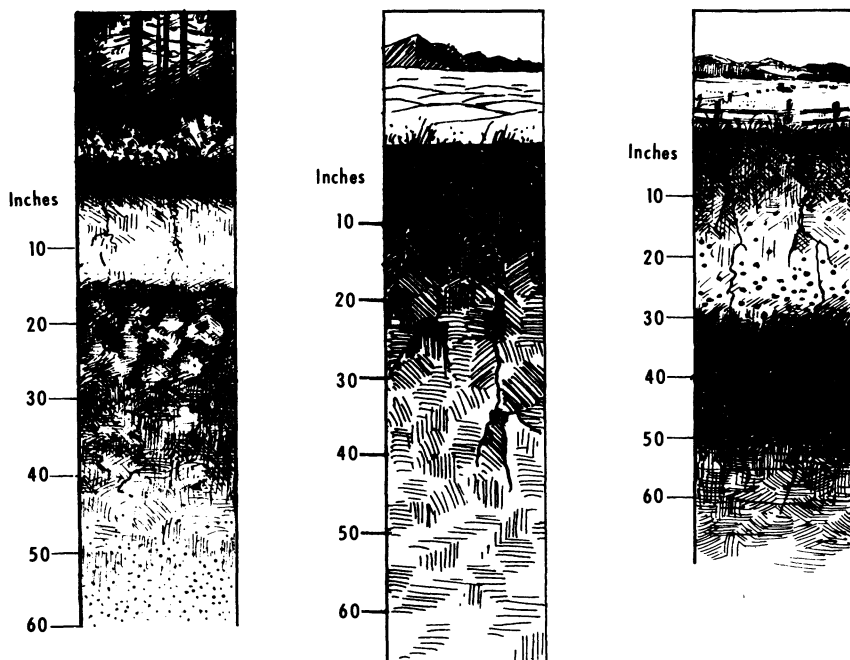


FIGURE 2.—Different kinds of soil have different management problems and potential for food crop production. The soil on the left is formed under coniferous forests of the Northeastern United States. Most of these soils are used for forestry, although some areas are used for blueberries or potatoes. Pastures grown on these soils usually contain too little cobalt and selenium for grazing animals. The soil in the center is formed under grasses on the plains of the West Central United States. Soils like these are usually excellent for production of bread wheat. Drought is an important problem on these soils. The soil on the right is formed in poorly drained areas under mixed grass and forest vegetation. If these soils can be effectively drained and are properly fertilized, they may produce good yields of soybeans, corn, and other cereals. (Drawings by C. C. Nikiforoff.)

digestive tract and is excreted in the feces. Various plants differ in the extent to which the elements in them are digested by animals.

At every step in their movement in the food chain from soils to animals, the essential mineral elements interact with other elements, and these interactions may profoundly affect the availability of essential elements to plants or animals or the amount of the essential element required for normal growth or metabolic function. Thus, a high level of soluble iron in the soil may depress the solubility of phosphorus and cause plants to suffer from phosphorus deficiency. At the surface of the roots a high level of potassium may interfere with the uptake of magnesium by plants. The availability of dietary zinc to animals may be depressed if the diet is high in calcium, and high levels of dietary molybdenum may interfere with copper metabolism in animals. These and other interactions must be considered in assessing whether a given

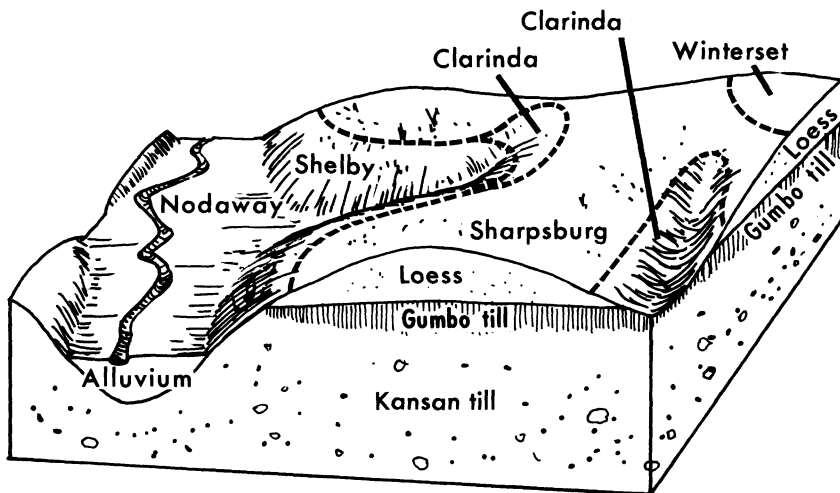


FIGURE 3.—Soils with different problems and potential uses may occur close together in the same landscape. The Winterset and Sharpsburg soils on the hilltops in this drawing are excellent soils for production of corn and soybeans. The Clarinda soils are poorly drained and very hard to till, but in some places these soils are good sites for farm ponds. The Shelby soils occupy sloping positions and may erode if they are used for cultivated crops, and so they are generally used for pasture. The Nodaway soils are usually fertile and very productive, but some areas of these soils are hazarded from flooding. (Adapted from Taylor County Iowa Soils, U.S. Dept. Agr., 1947.)

soil will supply plants, or a given plant will supply animals, with required amounts of any nutrient element.

The transfer of essential nutrient elements from soils into plants and then into animal tissues is therefore a complicated process. Each of the essential nutrients may follow its own unique pathway, and its movement may be regulated by specific mechanisms as it moves along the food chain. In the following discussion specific elements are considered, and some of the factors affecting their movement from soils to animals or man are described.

Boron

Boron (B) is required by plants, but it has not been found to be needed by animals. Boron deficiency may change the levels of vitamins or sugars in plants owing to the effect of B on synthesis and translocation of these compounds within the plant. The addition of B to some B-deficient soils has increased the carotene or provitamin A concentration in carrots and alfalfa.

Although B is required by plants, high levels of soluble B are toxic to plants. Different plant species vary widely in their requirement for this element and in their tolerance for high levels of B. Applications of B fertilizer must be carefully adjusted for different crops. An

application of B fertilizer to improve yields of alfalfa or beets may be toxic to such B-sensitive crops as tomatoes or grapes. In the South-western United States serious B toxicity to plants has resulted from using irrigation waters high in B.

Calcium

Calcium (Ca) is required in fairly large amounts by both plants and animals and is a very important constituent of bones and teeth. Deficiencies of Ca sometimes limit plant growth, and Ca deficiency may result in rickets in children and defective eggshells in birds. There is also evidence that osteoporosis among older people is associated with Ca deficiency.

The soils of humid regions are commonly low in Ca, and ground limestone is usually applied to add Ca, reduce the toxicity of aluminum and manganese, and correct soil acidity. The soils of dry areas are frequently rich in Ca.

In view of the relatively high requirement for Ca by humans and animals and the wide differences in available Ca in soils of different regions, Ca deficiencies in humans or animals might be expected to be directly related to levels of available Ca in soils. However, there is very little evidence that this relationship exists in human nutrition, and even in farm livestock most Ca deficiencies are not related to levels of available Ca in the soil. The reason for this anomaly is evident when one examines some of the controls over the movement of Ca in the food chain.

At the step in the food chain when Ca moves from the soil to the plant, controls based on the genetic nature of the plant are very important. Because of these controls certain plant species always accumulate fairly high concentrations of Ca and others fairly low concentrations. Among the forage crops, red clover grown on the low Ca soils of the Northeastern United States contains more Ca than grasses grown on the high Ca soils of the West. Among the food crops, snap beans and peas normally contain about three to five times as much Ca as corn or tomatoes. So the level of Ca in the diet of people or of animals depends more on what kind of plants are included in the diet than it does on the supply of available Ca in the soil where these plants are grown.

A second major factor controlling the Ca nutrition of people or animals is the supply of vitamin D. People and animals deficient in vitamin D do not utilize the Ca in their diets as well as those with an adequate supply of vitamin D. Adding vitamin D to foods has helped to prevent rickets due to Ca deficiency in children in the United States. Vitamin D deficiency is more common among people who have limited exposure to direct sunlight, which stimulates synthesis of this vitamin in the skin.

In many countries milk is a major source of Ca for human diets. A cow deficient in Ca will usually give less milk than a comparable cow fed a diet adequate in Ca, but the concentration of Ca in the milk of the two cows will be essentially the same.

Milk fever is a conditioned Ca deficiency that occurs in cows early in the lactation period. It is especially likely to strike high milk-producing cows. Although the exact nature of this problem is still obscure, it appears to be due to the inability of the cow to mobilize her body reserves of Ca to meet the excessive demand for Ca needed for the high production of milk during early lactation. Adding higher levels of Ca to the cow's diet will not always prevent milk fever.

Deficiency of Ca, uncomplicated by deficiency of vitamin D or by unfavorable ratios of Ca to phosphorus, has been observed where cattle are grazed on pastures containing grasses but no legumes, and these pastures are produced on acid, low Ca soils. When farm livestock are fed diets compounded primarily from cereal grains, Ca deficiency may occur. The grains are ordinarily very low in Ca and have unfavorable ratios of Ca to phosphorus, regardless of the level of Ca in the soils where the grains are produced. Adding Ca mineral supplements to the diet of grain-fed cattle, hogs, poultry, and sheep is a very common practice in modern farming.

Adding limestone to soils to correct soil acidity and to supplement available Ca can have substantial indirect effects on human and animal nutrition. By liming acid soils the farmer can usually grow crops that would not grow at all on the unlimed soil. He may be able to grow a high Ca crop, such as alfalfa or peas, in a field where only low Ca grasses would grow before liming, or he may be able to change to dairy farming from the production of acid-tolerant cash crops. Although Ca deficiency may be due more directly to improper food selection than to the effects of the soil on the Ca level in any one kind of plant, the use of limestone may offer people and animals a better chance to have foods high in Ca.

Chlorine

Chlorine (Cl) is required by both plants and animals, but so-called "field" cases of Cl deficiency in either plants or animals have been extremely rare. The addition of salt to human and animal diets has been a common practice for centuries. Although the primary reason for salt supplementation of most diets is to improve flavor, the chloride in the salt insures adequate intake of this element by people and animals. Chlorine is present in the water from many wells and streams, and it is often added to water during purification for domestic use.

The Cl in rainfall may be sufficient to meet the requirements of plants for this element. Chlorine is also an accessory constituent of

many fertilizers. Chlorine or chloride toxicity to plants is more common than Cl deficiency. Many irrigation waters contain sufficient Cl to cause tipburn on the leaves of irrigated crops.

Since the addition of common salt to human and animal diets is so widespread and provides a simple way of meeting Cl requirements, there is no concern over relationships between Cl in soils and the nutritional quality of crops.

Chromium

Chromium (Cr) is one of the most recent elements to be added to those required by man and animals. Certain compounds of Cr may activate insulin during sugar metabolism in the human or animal body. In Cr deficiency the utilization of glucose is slowed down, and some persons with diabetes have responded better to treatment with insulin plus Cr than to insulin alone.

Not all the various chemical forms of Cr are effective in improving sugar metabolism, and the exact nature of the compound or compounds involved in activating insulin is still unknown. Some of the Cr in plants may not be present in nutritionally effective forms.

Chromium is not essential to plants. High concentrations of Cr are toxic to plants. Most agricultural crops, especially their seeds, contain only low levels of Cr.

Until additional research is done, it is impossible to predict whether the nutritional quality of plants can be improved by adding Cr to soils.

Cobalt

Cobalt (Co) moves from the soil into plants. When these plants are eaten by ruminants, such as cattle, sheep, and goats, the Co is combined with other materials in the rumen to form vitamin B₁₂, a specific organic compound of Co. As the food material moves down the digestive tract, the vitamin B₁₂ is absorbed from the gut and performs many essential functions in the ruminant body. When single-stomached animals, such as man or pigs, drink milk or eat meat from ruminants, the vitamin B₁₂ in the milk or meat is absorbed to meet requirements for this vitamin.

Although Co is an essential element for man and animals, it can perform its essential functions only after it has been incorporated into the vitamin B₁₂ molecule. The micro-organisms living in ruminants are the major producers of vitamin B₁₂ in the food chain. Green plants are the major producers of vitamin B₁₂. People get their required B₁₂ from animal products, such as milk, cheese, meat, and eggs. Those who follow a strictly vegetarian diet without milk, cheese, or eggs are very likely to become deficient in vitamin B₁₂. Single-stomached domestic and wild

animals get their vitamin B₁₂ from animal flesh or from animal fecal material.

Cobalt is required by the micro-organisms that live in nodules on the roots of legumes, such as beans and clovers. They convert nitrogen from the air into chemical forms that can be used by higher plants. This is the only known function of Co in plant growth. Legumes may grow normally and the micro-organisms on their roots fix atmospheric nitrogen, even though the forage does not contain enough Co to meet the requirements of ruminants.

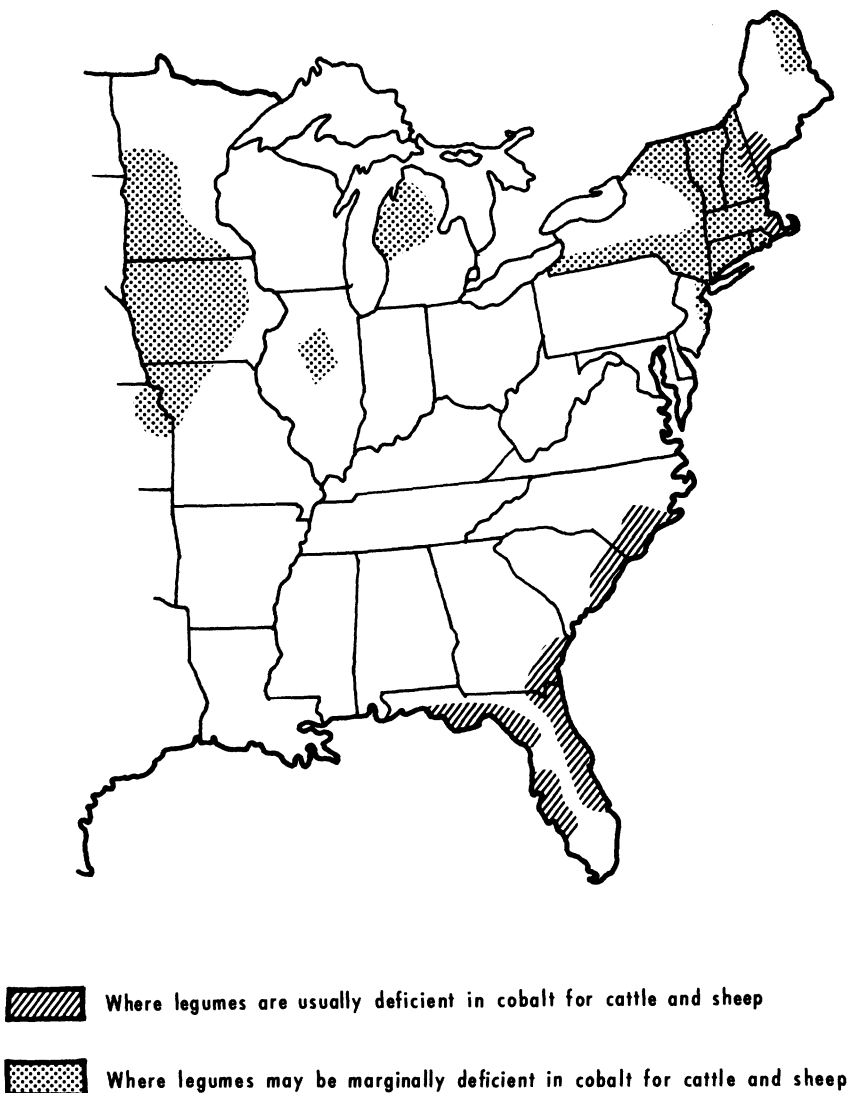
Areas of low Co soils in the United States, where clovers and alfalfa are too low in Co content to meet requirements of cattle and sheep, are shown in figure 4. The low Co soils of New England are primarily sandy and were formed from glacial deposits near and to the south of the White Mountains of New Hampshire. Along the South Atlantic Coastal Plain, legumes with very low concentrations of Co are primarily on the sandy soils formed in naturally wet areas. These soils, which are called Spodosols, have light-colored subsurface layers overlying a dark-brown or dark-gray hardpan layer.

Grasses and cereal grains generally contain less than the 0.07 to 0.10 parts per million of Co required by ruminants. Cattle and sheep that are not fed any legumes nearly always require Co supplementation.

Adding Co to soils, either as cobalt sulfate or as cobaltized superphosphate, can be used to increase the level of Co in plants and prevent Co deficiency in cattle and sheep. Since excessive levels of Co are not very toxic to either plants or animals, no appreciable hazards are likely in adding Co to soils. Cobalt fertilization may not be effective in preventing Co deficiency on alkaline soils, because in these soils the added Co quickly reverts to forms that are not taken up by plants. Cobalt fertilization is more common in Australia than in the United States. In the United States, Co is usually added to mixed feeds, mineral mixes, or salt licks.

Still another method is to place heavy ceramic "bullets" containing Co in the animal's rumen. These bullets stay in the rumen and slowly release Co to meet animal needs for a long time. The diets of hogs and chickens are often supplemented with concentrated forms of vitamin B₁₂.

The relationship of the levels of Co in soils and plants to the health of ruminants is one of the striking examples of a soil and plant relationship to animal health. When some Australian scientists discovered this relationship, new areas in several parts of the world became usable for animal production. The vitamin B₁₂ formed within cattle and sheep in these new areas contributed to the vitamin B₁₂ nutrition of people, even though adding Co to soils does not directly affect human nutrition in the absence of the production of ruminants.



 Where legumes are usually deficient in cobalt for cattle and sheep

 Where legumes may be marginally deficient in cobalt for cattle and sheep

FIGURE 4.—Areas in the United States where legumes contain low levels of cobalt.

Copper

Copper (Cu) is required by both plants and animals. Copper deficiency in plants is most frequent on organic soils, such as newly drained bogs, and on very sandy soils. The severe Cu deficiency often found when bogs and marshes are first used for crop production is called reclamation disease in some parts of the world.

Ruminants are sensitive to Cu deficiency. The symptoms of Cu deficiency in animals vary with the species and age, but often the

fading of brown or black hair is evident. On some acidic soils the use of Cu in fertilizers increases crop and pasture production, and the increases in level of Cu in the plants help to prevent Cu deficiency in the cattle and sheep. In parts of Australia, livestock production was impossible until Cu fertilizers were used on the pastures. Application of Cu fertilizers to alkaline soils generally does not increase the Cu level in the crop. Farm animals are often supplied with Cu in the form of dietary mineral supplements.

Although Cu fertilizers will sometimes increase crop yields and improve the nutritional quality of the crops, this practice must be used with caution and only on Cu-deficient soils. Both plants and animals are subject to toxicity from excessive levels of Cu. Ruminants, especially sheep, are sensitive to Cu toxicity as well as to Cu deficiency. Adding a Cu fertilizer to a soil that naturally contains high levels of available Cu may increase Cu levels in the forage to the point of causing its toxicity in grazing sheep. Copper toxicity from soils naturally high in Cu occurs in Australia but is uncommon in the United States. There are soils in the United States, however, that produce forages with levels of Cu close to toxicity limits, and if Cu-bearing mineral supplements are inadvertently used with these forages, Cu toxicity to sheep may result.

It is not always possible to set a definite limit, in terms of the Cu concentration in the diet, that will permit accurate predictions of the danger of Cu deficiency or of Cu toxicity in cattle and sheep. In particular, if the molybdenum concentration in the forage is high, extra amounts of Cu are needed to prevent deficiency; also, higher Cu levels can be tolerated without danger of toxicity.

Monogastric animals, including man, are less sensitive than ruminants to both Cu deficiency and Cu toxicity. Copper deficiency in people has been found only when other complications, such as excessive bleeding, general starvation, and iron deficiency, are also present. Wilson's disease, an inherited disease of man, prevents the loss of excess Cu from the body and brings on Cu toxicity. No direct relationships have been found between levels of available Cu in the soil and the Cu status of man.

Fluorine

In nature the element fluorine (F) is always found combined with other elements in compounds called fluorides. Fluorides are not required for plant growth. In animals and man low levels of fluorides have beneficial effects on teeth and on bone structure. Growth increases in experimental animals have been reported when low levels of fluorides have been added to purified diets. Fluorine may soon be considered one of the essential elements for animals. Excessive levels of certain F compounds are very toxic to both animals and plants, and F

toxicity in both animals and plants has been a serious problem where fumes and dusts have been emitted from industrial plants or from volcanoes. High levels of fluoride in water have also caused F toxicity in animals and mottled teeth in people.

Fluorides do not usually move from the soil to plants and on to human and animal diets in amounts that are toxic to humans and animals. Injury to plants from fluoride in the soil has been noted on soils that are too acid for satisfactory growth of most plants. On limed soils or soils with enough calcium (Ca) for optimum plant growth, any F added to the soil reacts with the Ca and other soil constituents to form insoluble compounds, which are not taken up by plants. Rock phosphate and some kinds of superphosphate fertilizers contain large amounts of calcium fluoride, but the F content of the plants grown on soils that have been heavily fertilized with these phosphates is not appreciably increased. Tea and some other members of the *Theaceae* family are the only plants that take up very much F from the soil.

The soil-to-plant segment of the food chain contains some built-in safeguards against F toxicity. This toxicity has been due to the deposition of airborne fumes and dusts on the aboveground parts of plants, followed by the consumption of these contaminated plants by animals and man. Also, F toxicity has been caused by direct inhalation of the fumes and dusts or by drinking water with high F levels. If the fumes and dusts are mixed into the soil, they will be inactivated and will not get into the food chain in toxic amounts.

The safeguards against toxicity provided by the chemistry of F in soils make it unlikely that applying F compounds to soils will be a useful way to insure that plants will contain sufficient F to prevent dental caries. Where increased fluoride intake is desirable for this purpose, carefully controlled direct additions to drinking water, to dentifrices, or to specific foods are more promising than adding fluorides to soils that produce food crops.

Iodine

The relationship between iodine (I) levels in the soils and in plants of different areas to the incidence of goiter among residents of these areas is the most striking example of an effect of soil on human health. The discovery that goiter is due to iodine deficiency and the understanding of factors that control the levels of iodine in soils and its movement into human diets, plus the development of iodized salt to prevent iodine deficiency, must be ranked as one of the great scientific contributions to improved human health.

Iodine is not required by plants, but if iodine is present in the soil, it is taken up by most plants and moves on into diets in forms that are effective in preventing goiter. In areas where the soils are high in iodine, ground water is also high in iodine, but the food supply is still

the major source of iodine for people in these areas. Seafoods are good sources of dietary iodine.

Many of the iodine-deficient regions of the world have been identified and can be shown on maps. They are generally either mountainous or in the center of continents, and they are very distant from the oceans in the prevailing wind direction. Studies of the geochemistry of iodine indicate that this element is volatilized from oceans, carried over land by winds, and deposited on the soil by rain. The mountainous areas are low in iodine because little of that volatilized from the seas reaches sufficient altitude to be deposited in high mountains. In some areas the younger soils have less iodine than the older ones because there has been less time for the geochemical processes to build up iodine levels in the soil.

Although the amount of iodine in the soil is the primary factor determining iodine levels in food crops from different regions, the level of iodine in plants and the dietary requirements for iodine are modified to some extent by the plants themselves. There are important differences among plant species, and even among varieties of the same species, in their tendency to take up iodine from the soil. Certain plants, especially some of the *Brassica* genus such as cabbage, contain compounds called goitrogens, which interfere with the effect of iodine on the thyroid gland. The amount of iodine required to protect animals and people against goiter depends on the kinds of plants in the diet as well as on the iodine level characteristic of the soils of the region.

Iodine in food crops can be increased by adding iodine compounds to soil, but this is a very inefficient way of insuring adequate dietary levels of this element. Much of the iodine added to the soil would be leached out and returned to the seas before it could be taken up by the crop plants. The use of iodized salt is such an effective way of supplying this element to people and animals that there is little need to include iodine in fertilizers.

Iron

Iron (Fe) deficiency is a serious problem in crop production in certain areas, and some nutritionists consider iron deficiency anemia to be the most frequently observed mineral element deficiency in people. But Fe fertilization of soils is not likely to be effective in decreasing the incidence of Fe deficiency in people. The reasons for this apparent contradiction are based on the behavior of Fe at several stages in the food chain.

Severe Fe deficiency in crop plants most often occurs on the alkaline soils of the Western United States and on very sandy soils, although some plants, especially broad-leaved evergreens such as azaleas, are frequently Fe deficient on many other kinds of soil. Iron deficiency is

rarely due to a total lack of Fe in the soil; it is nearly always due to the low solubility of the Fe that is present. Some soils that are red from Fe compounds may contain too little available Fe for normal plant growth.

To correct Fe deficiency in plants, it is usually necessary to add a soluble form of Fe to the soil or to spray the foliage. Since soluble Fe added generally will revert to insoluble forms, these procedures for correcting Fe deficiency in plants are only temporarily effective. Soil treatments that make alkaline soils more acid, such as incorporating large amounts of sulfur, may offer a more lasting correction of Fe deficiency. Incorporating large amounts of farmyard manure into the soil makes the Fe more soluble and may be effective in correcting Fe deficiency, especially in fine-textured alkaline soils.

Iron-deficient plants are generally stunted and chlorotic, that is, normally green leaves are yellow or streaked with yellow. When the Fe deficiency is treated by adding soluble Fe to the soil, the plants turn green, grow larger, and yield more, but sometimes the concentration of Fe per unit weight of plant material may be no higher than in the stunted Fe-deficient plants. So correction of Fe deficiency in the plant does not necessarily improve the plant as a source of dietary Fe. The Fe-treated plants may, however, contain a higher concentration of carotene or provitamin A than the yellow, stunted, Fe-deficient plants. So Fe fertilization may be more useful in improving the vitamin A than the Fe level in diets.

Iron deficiency in people is usually associated with loss of blood or the inefficient utilization of dietary Fe. Women of childbearing age and people suffering blood loss due to internal parasites are susceptible to Fe deficiency. Since the Fe contained in meats is generally more effectively utilized than that in foods of plant origin, proper food selection may effectively prevent Fe deficiency. Certain processed foods are fortified with Fe. Direct supplementation of human diets with Fe plus vitamin pills is also common.

In farm livestock, Fe deficiency is most common in young pigs raised in confinement on concrete floors. Injecting Fe compounds and painting the sow's udder with Fe compounds are used to prevent this deficiency on modern pig farms. Grazing animals almost never suffer from Fe deficiency unless they are heavily parasitized.

Although Fe deficiency is very common in both plants and people, there is little or no direct relationship between Fe-deficient plants and Fe-deficient people. The Fe deficiencies of plants must be corrected to obtain satisfactory crop yields, but this will rarely have any effect on Fe deficiencies in people who eat these plants. Iron deficiencies in people can be corrected more effectively by Fe supplements, food fortification, improved food habits, and control of internal parasites.

Magnesium

Magnesium (Mg) is an integral part of the molecule of chlorophyll, the green pigment in plants that captures energy from the Sun. Magnesium deficiency is a fairly common cause of poor crop yields, especially among crops produced on sandy soils.

The accumulation of Mg from the soil by plants is strongly affected by the species of plant. The leguminous plants, such as clovers, beans, and peas, usually contain more Mg than grasses, tomatoes, corn, and other nonleguminous plants, regardless of the level of available Mg in the soil where they grow.

A very high level of available potassium (K) in the soil interferes with the uptake of Mg by plants, and Mg deficiency in plants is often found on soils that are very high in available K. High levels of available K may occur naturally, especially in soils of subhumid and semi-arid regions, or they may be caused by heavy applications of certain commercial fertilizers or animal manure. On sandy and loamy soils, applications of Mg fertilizers are often effective in increasing crop yields and the concentration of Mg in the crop, but on fine-textured clayey soils, especially those with substantial reserves of K, the application of a Mg fertilizer may not result in higher Mg concentrations in the crop.

The most dramatic cases of Mg deficiency in farm animals are in lactating cows. "Grass tetany" and "grass staggers" are common names for acute Mg deficiency. This deficiency usually strikes older lactating cows that are being grazed on certain grasses in the spring, fall, or winter. Some cases also occur during the winter if lactating cows are being fed on low Mg grass hay. Affected cows become nervous, then stagger and fall. If the disorder is detected in time and the cows are injected with Mg, they will recover and return to normal within a few minutes. Where the problem is not detected, the cows frequently die soon after they fall.

Not all the factors causing grass tetany are understood. The grasses eaten by the cows are usually low in Mg and high in K. Frequently the concentration of nitrogen and certain organic acids is also high. The disease is seasonal, and severe outbreaks occur during some years, whereas it is uncommon among cattle grazing the same pastures in other years. In all cases, problems of Mg metabolism in the animals are apparent, and the level of Mg in the blood serum is low.

Maintaining a high daily intake of Mg seems to be essential to prevent grass tetany in cows. On some pasture soils this high daily intake of Mg can be achieved by using heavy applications of Mg fertilizers or high Mg liming materials so that the Mg concentration in the grass will be maintained at a high level. Some farmers dust or spray their pastures with magnesium oxide or other Mg compounds so that they

adhere to the grass and are eaten directly to maintain high daily intake. Others use a mineral supplement containing Mg plus an appetizer like molasses, or they give a daily feeding of a high Mg legume hay to prevent grass tetany.

Since Mg is not one of the highly toxic elements in either plants or animals, precautions against its overuse are rarely necessary. When animals are fed diets primarily of grains, a proper balance among Mg, calcium, and phosphorus should be maintained to minimize danger from urinary calculi.

Some medical research indicates that Mg deficiency in people may cause neuromuscular problems. This deficiency is usually associated with kidney malfunction. The extent to which this deficiency in people is caused by diets deficient in Mg has not been established. There is no current evidence of any relationship between levels of Mg in soils where food crops are grown and the occurrence of Mg deficiency in people. Even so, soil-management practices designed to maintain high levels of Mg in food crops would seem to be desirable and will probably receive additional emphasis from agricultural research workers in the future. Foods of plant origin are a major source of Mg in human diets.

Manganese

Manganese (Mn) is required by both plants and animals. Although its deficiency is normally a problem in small areas of fields, it has caused economic losses in the production of cereal small grains on some alkaline soils. In acid soils Mn is more soluble, and plants may be damaged by excessive uptake of this element. Reduced crop yields due to Mn toxicity on acid soils are probably responsible for greater economic losses in the United States than are reduced crop yields caused by Mn deficiency. Measurement of the total Mn concentration in any soil is of little value for predicting possible Mn deficiency or toxicity. The amounts of soluble Mn are more directly related to the level of Mn in plants, but soluble Mn in the soil may fluctuate over short periods because of flooding or drying of the soil or the addition of fresh organic matter.

The concentration of Mn in food and feed plants varies widely and is more dependent on the acidity or alkalinity of the soil than on the amount of Mn used in fertilizers.

Chickens are frequently subject to Mn deficiency, especially when their ration contains large amounts of corn. Manganese deficiency in chicks causes a deformity of the legs. This deformity has been traced back to a need for Mn in the formation of the organic matrix, which is later calcified in the process of bone formation. Rations for growing chickens are nearly always supplemented with extra Mn on commercial poultry farms in the United States. Cattle, hogs, and sheep are less

often subject to Mn deficiencies than are chickens. Even so, some cases of reproductive failure and some deformities in the young have been attributed to Mn deficiency in these species.

Relationships between a low level of available Mn in the soil where feed crops are produced and Mn deficiencies in animals and chickens have not been established. Manganese is not very toxic to animals, and the most practical method of preventing this deficiency is to add Mn salts to the feed or to mineral mixes consumed by animals. Adding Mn to the soil where the feed crops are grown probably would not be effective in preventing Mn deficiencies in farm animals and poultry.

There have been no authenticated cases of Mn deficiency in people, and their minimum daily requirement for Mn is not known. Cereals and pulses (peas and beans) are major sources of Mn in human diets, and diets containing these foods can be expected to have adequate Mn.

Molybdenum

Molybdenum (Mo) is required in very low amounts by both plants and animals. Uncomplicated deficiencies of Mo are not very common in either plant or animal nutrition, but nutrient imbalances involving Mo and copper (Cu) have caused serious problems in cattle and sheep production.

Molybdenum deficiencies are found in plants grown on certain acid soils, and sometimes the deficiency can be corrected by adding either a few ounces of Mo per acre in fertilizer or a few tons of limestone per acre. The limestone makes the soil more alkaline and increases the availability of the native Mo in the soil. In parts of the Eastern United States small amounts of Mo fertilizer are regularly used for producing certain vegetables, especially cauliflower. In Australia, large areas have been changed from near desert to productive farms through the application of molybdenized superphosphate supplying just a few ounces of Mo per acre.

In alkaline soils Mo is more available to plants, and forage crops growing on some alkaline soils in the Western United States may take up high concentrations of Mo. This Mo is not toxic to the plants, and they grow normally and may produce excellent yields. But cattle and sheep that eat these forages may suffer from Mo toxicity. Molybdenum toxicity is actually a Mo-induced Cu deficiency. The symptoms of Mo toxicity are identical with those of Cu deficiency and include fading of the hair and diarrhea. It may be prevented by supplementing the animal diet with extra Cu or by injecting Cu compounds into the animal body. Cattle are more susceptible to Mo-induced Cu deficiency than other types of livestock. Horses and pigs are rather tolerant of high levels of dietary Mo.

High levels of Mo are generally considered to be 20 parts per million or more in the dry forage. Some symptoms of interference with

Cu metabolism in cattle may be evident when the forage contains as little as 5 parts per million of Mo if it is also low in Cu. The effects of high Mo forage in interfering with Cu metabolism in animals are generally more severe if the animal diet is also high in sulfates.

Soils producing forages with high levels of Mo are generally confined to valleys of small mountain streams in the Western United States. Only a very small part of any valley actually produces high Mo forages. These soils are wet or poorly drained, alkaline, high in organic matter, and the alluvium from which they were formed was originally derived from granites or high Mo shales.

A typical area where high Mo forages grow and the effect of these forages on cattle are shown in figure 5. Molybdenum toxicity in cattle has also been found where dusts from Mo-processing industry or waste water from the tailings of uranium mines has contaminated pastures. Molybdenum toxicity has also occurred in cattle grazing pastures on organic soils in Florida.

The most effective method of preventing Mo toxicity in cattle and sheep is to provide the animals with a mineral supplement or salt lick

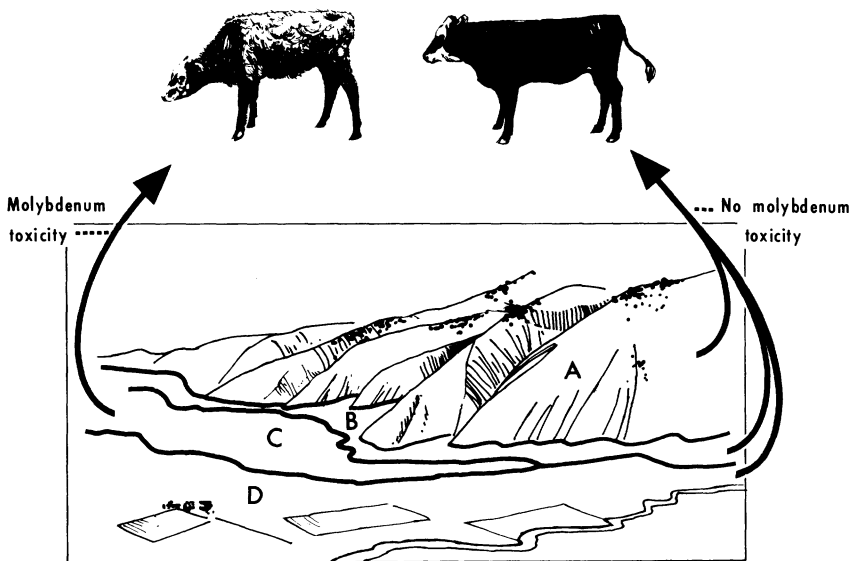


FIGURE 5.—Plants containing toxic levels of molybdenum (Mo) are found only on wet soils formed from high Mo parent materials. In this drawing of a Nevada mountain valley the wet Ophir soils (C) produce high Mo forage and cattle eating these forages are usually emaciated and their dark hair fades. Forages growing on the well-drained Mottsville (B) and Toiyabe (A) soils are lower in Mo and cattle grazing these forages are normal in appearance. The Mo in the parent material of Mottsville and Toiyabe soils is not available to plants. The Bishop and associated soils (D) in the center of the valley are formed from parent materials lower in Mo, and even though these soils are wet, they produce low Mo forages.

fortified with Cu. Injection of organic compounds of Cu under the animal's skin is also very effective. The use of Cu fertilizers to increase the Cu concentration in the forages produced is not effective because on these alkaline soils the added Cu is converted to forms that are not well utilized by plants.

There have been no reports of Mo deficiency or toxicity among people from foods produced in the United States. Some research in New Zealand and the British Isles indicates that diets containing moderately high levels of Mo may help to prevent dental decay. The high Mo soils of the United States are seldom used for production of food crops. Effects of Mo in soil or Mo levels in food crops on the dental health of people in the United States have not been evident.

Phosphorus

Phosphorus (P) is required by every living plant and animal cell. Deficiencies of available P in soils are a major cause of limited crop production. Phosphorus deficiency also is probably the most critical mineral deficiency in grazing livestock.

When P fertilizers are added to soils deficient in available forms of this element, increased crop and pasture yields ordinarily follow. Sometimes the P concentration in the crop is increased, and this increase may help to prevent P deficiency in the animals eating this crop, but this is not always so. Some soils convert P added in fertilizers to forms that are not available to plants. On these soils very heavy applications of P fertilizer may be required to obtain increased crop yields, and very little increased concentration of P in the crop is obtained. Some plants always contain low concentrations of P regardless of the fertility of the soil on which they are grown.

Some of the complex relationships between P levels in soils and P nutrition of animals are shown in figure 6. This graph shows the percentage of P in oats and alfalfa grown in Iowa on Clarion loam that was fertilized with different rates of P fertilizers and seeded to a mixture of the two crops. In this experiment the yield of both oats and alfalfa was markedly increased by P fertilization. Cattle require about 0.3 percent of P in their diets for optimum growth, as indicated in the graph. The oat straw contained less P than needed by cattle even at the highest level of P fertilization applied. The oat grain contained enough P to meet the dietary requirements of cattle even when grown on the unfertilized plots. This is typical of many grain crops—if they grow at all, the grain will generally contain enough P for cattle. The use of P fertilizer changed the alfalfa from a crop containing too little P to meet the requirements of cattle to one that would be adequate in this respect.

Decisions on how to most effectively prevent P deficiency in plants and in animals are generally based on the expected effect of P fertil-

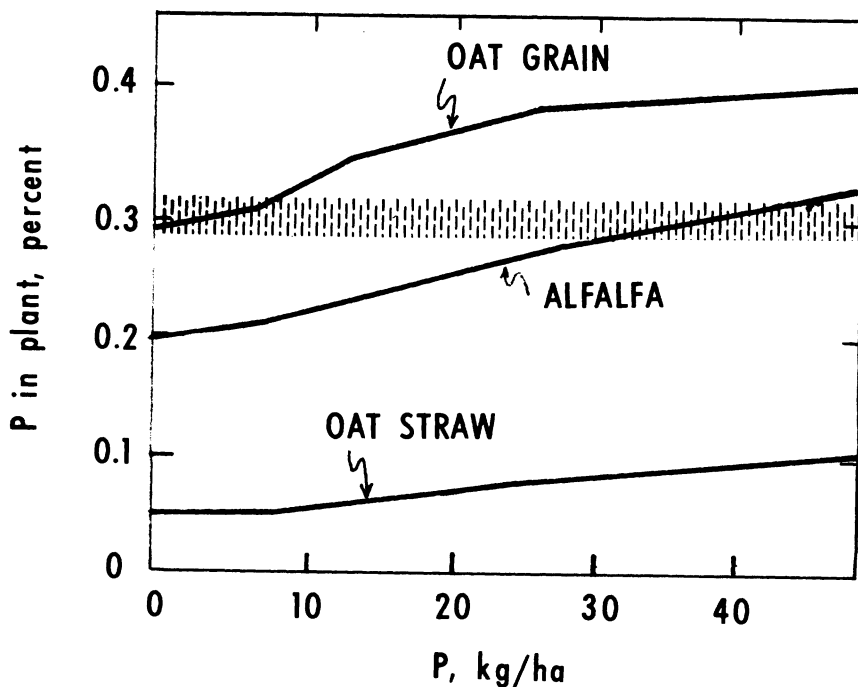


FIGURE 6.—Effect of rate of phosphorus (P) fertilizer application on concentration of P in oats and alfalfa grown on Clarion loam. About 0.3 percent of P (dashed line) is required by dairy cattle for normal growth.

izers on crop and pasture yields. If an increased yield can be expected, P fertilizers are used to obtain this increase, and the effect of the fertilizer on P concentration in the crop is of secondary importance. If an increased yield of the crop seems unlikely, animals whose rations are likely to be deficient in P are usually provided with mineral supplements containing this element. In some of the drier range and pasture areas, yields of the plants are limited by lack of moisture regardless of the level of available P in the soil. In these situations the use of P-fortified mineral supplements fed directly to livestock is the only practical method of meeting their P requirements.

Cereals and meats are major sources of P in human diets. Phosphorus deficiencies have not been a serious problem in human nutrition. As far as human food is concerned, the primary value of P fertilizers is that they generally increase the total food production in any area.

Potassium

Potassium (K) is required by both plants and animals. Although the total amount of K in most soils is usually rather high, the level of available or soluble forms of K is frequently too low to meet the needs of growing plants. Deficiencies of plant-available K are more frequent

in the soils of the Eastern than the Western United States. Potassium in the form of soluble K salts is a very common constituent of fertilizers.

Many plants will not grow at normal rates unless the plant tissues, especially the leaves, contain as much as 1 or 2 percent of K, and for some plants even higher concentrations are required. Therefore if a plant grows at all, it will nearly always contain sufficient K to meet the requirement of the human or animal that may eat the plant. Potassium deficiencies do occur in people and animals but this is due to metabolic upsets and illnesses that interfere with the utilization of K in the body or to excessive losses of K from the body rather than to inadequate levels of dietary K.

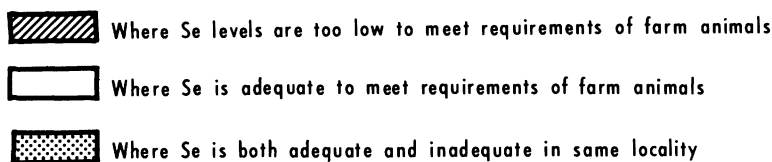
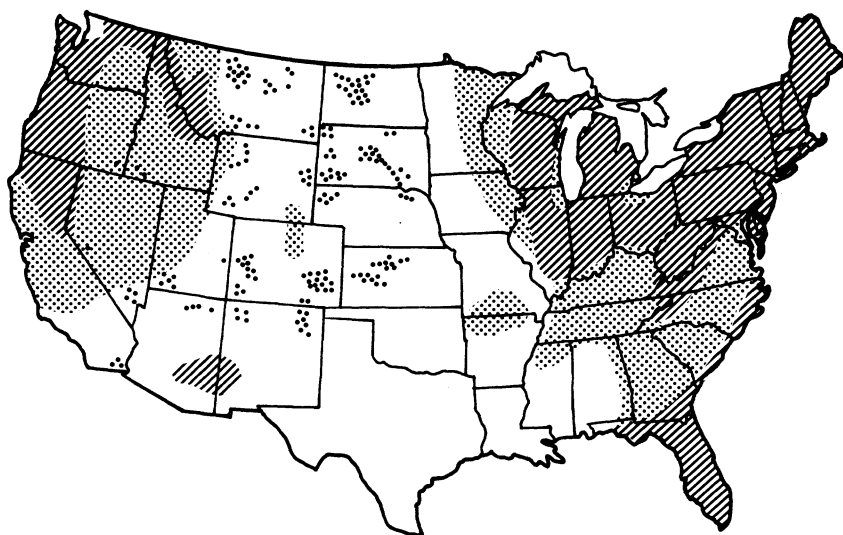
The role of K fertilizers in improving human and animal nutrition is to help increase food and feed supplies rather than to improve the nutritional quality of the crops produced. Excessive use of K fertilizers may decrease the concentration of magnesium in crops. For the effects of this decrease, see page 19.

Selenium

Some of the most dramatic examples of the effect of soils on the nutritional quality of plants are associated with selenium (Se). It has not been found to be required by plants, but it is required in very small amounts by warmblooded animals and probably by people. Still larger amounts of some Se compounds are very toxic to animals and people.

In large areas of the United States the soils contain very little Se in forms that can be taken up by plants. Crops produced in these areas are therefore very low in Se, and Se deficiency in livestock is a serious problem. Other large areas of the United States have soils that provide crops with Se levels adequate to meet the dietary requirements of livestock without causing toxicity in animals. In some areas in the Plains and Rocky Mountain States the soils are rich in available forms of Se. The plants that grow there contain so much Se that they are poisonous to animals that eat them. These different areas are shown in figure 7.

One of the striking features of Se is that it occurs naturally in several compounds and these vary greatly in their toxicity and in their value in preventing Se deficiency diseases. In its elemental form, Se is insoluble and biologically inactive. Inorganic selenates or selenites and some of the selenoamino acids in plants are very active biologically, whereas some of their metabolites that are excreted by animals are not biologically active. In well-drained alkaline soils, Se tends to be oxidized to selenates and these are readily taken up by plants, even to levels that may be toxic to the animals that eat these plants. In acid and neutral soils, Se tends to form selenites and these are insoluble and unavailable to plants. Selenium deficiency in livestock is most often



- Where Se toxicity may be a problem

FIGURE 7.—Areas where forages and feed crops contain various levels of selenium (Se).

found on farms with acid soils and especially soils formed from rocks low in Se.

In 1934 the mysterious livestock maladies on certain farms and ranches of the Plains and Rocky Mountain States were discovered to be due to plants with so much Se that they were poisonous to animals grazing there. Affected animals had sore feet, lost some of their hair, and many died. Over the next 20 years scientists found that the high levels of Se occurred only in soils derived from certain geological formations of high Se content. Another important discovery was that a certain group of plants, called the Se accumulators, had an extraordinary ability to extract Se from the soil. These Se accumulators were primarily shrubs or weeds native to semiarid and desert rangelands. They usually contained 50 parts per million or more of Se, whereas range grasses and field crops growing nearby contained less than 5 parts per million of Se.

These discoveries helped farmers and ranchers to avoid the most dangerous areas when grazing their livestock. The best practical way

to counteract Se toxicity problems is to limit grazing of the more highly seleniferous spots. Range-management practices that encourage the spread of perennial grasses and eliminate Se accumulator plants can also be useful. At one time there were some indications of toxic effects of Se among people living on farms in the seleniferous areas and producing a large part of their own food on these farms. With the changes in type of farming since the 1930's, most of these farms have been abandoned and the seleniferous areas are generally used as rangeland.

In 1957 Se was found to be essential in preventing liver degeneration of laboratory rats. Since then research workers have found that certain Se compounds, either added to the diet or injected into the animal, would prevent some serious diseases of lambs, calves, and chicks. Selenium is an essential nutrient element for birds and animals and very likely for people.

In most diets used in livestock production, from 0.04 to 0.10 parts per million of Se protects animals from the Se deficiency diseases. If the diet is very high in vitamin E, the required level of Se may be even lower than these estimates. In the earlier research on Se toxicity, diets containing more than 3 or 4 parts per million of Se caused reduced growth or infertility in animals and chickens.

Even though the relative differences between essential and toxic concentrations of Se are about the same as for many other components of diets, such as salt, these differences are small in terms of the amount of Se. Careful study is needed of the movement of Se from soils to plants and on into animal or human diets. Interest in the levels of Se in human diets may increase because of evidence that dietary Se may protect laboratory animals from the effects of certain cancer-causing chemicals.

When farm animals consume plants containing levels of Se adequate to protect them from Se deficiency diseases, the meat, milk, and eggs will contain more Se than that from animals fed low Se diets. Consequently, food products from animals can be a source of Se in human diets. Much of the wheat for breadmaking in the United States is produced in the Se-adequate sections of the country. Bread is generally a good source of dietary Se. Some evidence indicates that people living in the Se-adequate regions have higher levels of Se in their blood than those in the Se-deficient areas, but these differences are small and suggest neither Se deficiency nor toxicity among people living in the United States.

In the Se-deficient areas of the United States, farmers frequently inject young calves and lambs with small amounts of Se to protect them from this deficiency. Soluble selenate and selenites are being added to mixed feeds for pigs and poultry. Adding Se to Se-deficient farm soils to produce crops that contain enough Se to protect livestock

from Se deficiency diseases is not practical because it is inefficient and difficult to control.

Silicon

Silicon (Si) is an essential element for plants and animals. Scientists disagree as to whether it is required for all plant species. When laboratory animals have been confined in isolators where airborne dusts are excluded, their growth has improved if small amounts of Si compounds are added to highly purified diets containing all the other known essential components. Silicon appears to be required for the formation and functioning of connective tissue and for bone structure.

Silicon is one of the more abundant elements in the earth's crust and a major component of most soils. Low Si soils may be found on land surfaces exposed to weathering for a long time in tropical and subtropical zones, where the silica in the soil has been leached away by weathering to leave soils predominantly composed of iron and aluminum oxides. These soils are called Oxisols and Ultisols on modern soil survey maps.

Substantial increases in rice and sugarcane yields have been obtained by adding Si compounds when these crops are grown on Oxisols and Ultisols. The Si-treated crops have more erect, stronger stalks and resist wind damage better than those on untreated fields. Some Si-treated crops are more resistant to insects and plant diseases. Different plant species vary greatly in Si content. Members of the grass family and certain reeds or rushes often contain high levels of Si. The legumes, such as alfalfa and the clovers, take up very little Si, even when grown on Si-rich soils.

Some of the forage grasses if grown on soils with high levels of Si may take up sufficient Si to interfere with digestion of the carbohydrates and protein contained in these grasses when eaten by grazing animals. The effects of high Si levels in food plants on their nutritional value have not been studied.

Cattle and sheep are sometimes troubled by siliceous urinary calculi. Relationships between dietary intake of Si and the formation of siliceous calculi are still not clear. Some additional unknown dietary factor may also be involved in the formation of siliceous calculi.

No cases of Si deficiency in either people or farm animals have been noted. Additional research on Si in plant and animal nutrition will be needed before any relationship between Si in soils and the health of people or animals can be confirmed.

Sodium

All animals require sodium (Na). Adding salt to human and animal diets to supply Na is the oldest dietary supplementation practice. Some species of plants also require Na. This requirement for Na is depen-

dent on the biochemical pathway the different species use to capture energy from the Sun. Some of the most important food and feed crops do not require Na for normal growth, and their tissues normally contain much less Na than is required by animals or man.

Any attempt to meet the Na requirement of humans or animals through adding Na to soils where food and feed crops are grown would fail because some of these crop plants exclude Na from their tissues even though it is present in the soil in a soluble form.

Soils containing high levels of Na salts are often nearly barren because of Na toxicity and salt injury to plants. If the excess salts are leached out by drainage, some of the Na is held by the soil clay and the soil becomes hard and is not penetrated by roots. Reclamation of soil adversely affected by high levels of Na salts is a major problem in irrigation farming in semiarid regions.

Sulfur

Sulfur (S) is an important component of most proteins and an essential element for all plants and animals. In the chain from soils to plants to people, inorganic S, or more accurately the sulfate ion, SO_4 , is taken up by plants and converted within the plant to organic compounds called sulfur amino acids. Two of these sulfur amino acids, cysteine and methionine, are combined with other amino acids in plant protein. When the plant is eaten by a person or an animal, the protein is broken down and the amino acids are absorbed from the digestive tract and recombined in the proteins of the animal body. For a more detailed description of protein synthesis and protein nutrition, see page 37. The most important feature of S in the food chain is that plants use inorganic S compounds to make S amino acids, whereas animals and man use the S amino acids for their own processes and excrete inorganic S compounds resulting from the metabolism of these S amino acids.

Such ruminants as cattle, sheep, and goats can use inorganic S in their diets, because the micro-organisms in the rumen convert the inorganic S into S amino acids, and these are then absorbed farther along the digestive tract.

Soils very low in available S are common in the Pacific Northwest and in some parts of the Great Lake States. For many years S in the form of calcium sulfate was an accessory part of most commercial phosphate fertilizers, and this probably helped to prevent development of widespread S deficiency in crops grown where these fertilizers were used. Volatile S compounds from smoke are an important source of S for plants growing near industrial centers and may even be so prevalent as to injure plants growing close to sources of certain types of air pollution. The trend toward high analysis fertilizers without S and toward abatement of air pollution diminishes some of the inadvertent

sources of S for plants and is bringing about a need for more deliberate use of S fertilizers.

The extent to which any plant will convert inorganic S taken up from the soil into S amino acids and incorporate these into protein is controlled by the genetics of the plant. Increasing the available S in soils to levels in excess of those needed for optimum plant growth will not increase the concentration of S amino acids in the plant tissues. To meet the requirements for S amino acids in human diets, the use of food plant species with the inherited ability to build proteins containing high levels of S amino acids is required in addition to adequate supplies of available S in the soil.

Since animals tend to concentrate in their own proteins the S amino acids contained in the plants they eat, such animal products as meat, eggs, and cheese are valuable sources of the essential S amino acids in human diets. In regions where the diet is composed almost entirely of foods of plant origin, deficiencies of S amino acids may be critical in human nutrition. However, people in these areas are likely to be suffering from many other deficiencies at the same time and the precise cause of malnutrition cannot be pinpointed.

Diets of corn and soybean meal are usually fortified with S amino acids for pigs and chickens. Sometimes fishmeal, a good source of S amino acids, is added to the diets for this purpose, or S amino acids synthesized by industrial chemical procedures are used.

Since ruminants can utilize a wide variety of S compounds, any practice to increase the S in plants may help to meet the requirements of these animals. Sheep appear to have a higher requirement for S than most animals, perhaps because wool contains fairly high levels of S. Adding S fertilizers to soils used to produce forage for sheep may improve growth and wool production of the sheep, even though no increased growth of the forage crop itself is observed.

The addition of S fertilizers to soils where food crops are grown can improve human nutrition by increasing total food crop production, but the percentage of the essential S amino acids in these crops may be unchanged.

Zinc

Zinc (Zn) was one of the first so-called trace elements known to be essential for both plants and animals, and yet problems of Zn nutrition of plants, animals, and people are still of pressing importance. Evidence of Zn deficiency in crops is being recognized in new areas and the use of Zn in fertilizers has increased steadily. A dry, cracked condition of the skin of pigs called parakeratosis has been a Zn deficiency problem to pork producers. Some people in the United States and other countries may be suffering from Zn deficiency. Symptoms include

loss of appetite, loss of sense of taste, and delayed healing of burns, accidental wounds, or surgical incisions. Applying Zn ointments to promote healing of wounds and burns is an old practice in human medicine.

Laboratory animals deficient in Zn may be subject to serious reproductive problems, including infertility of males, failure of conception or implantation of the embryo, difficult births, and deformed offspring. The extent to which Zn deficiency is a primary cause of reproductive problems in farm animals and people is not known. Additional research on Zn nutrition may provide a basis for feeding practices leading to improved reproduction in farm animals.

Zinc deficiency in crops is frequently observed where fields have been graded to smooth them so that irrigation water can be applied more uniformly. Where the topsoil is cut away from small areas of these fields, such crops as corn or beans may be very stunted and many leaves will be white instead of green. If Zn fertilizers supplying as little as 10 pounds of Zn per acre are applied, bumper crops may be grown on these soils. Citrus trees are nearly always fertilized with Zn.

When Zn fertilizers are used on soils deficient in Zn, crop production may be increased even though the Zn concentration in the plant tissues and especially in the seed shows no increase. With higher levels of Zn fertilization, the Zn concentration in the plants may increase. There is some evidence that the value of food and feed crops as sources of dietary Zn can be improved by using Zn fertilizers at rates exceeding those necessary for optimum plant growth. Very high rates of Zn fertilization can depress crop yields. Even so, the margin of safety in use of Zn fertilizer is substantial, and few cases of Zn toxicity have been caused by its overuse. There are areas close to deposits of Zn-bearing ores where the soils naturally contain toxic levels of Zn.

The Zn contained in plants is not completely utilized by animals. Diets high in calcium and phosphorus have been associated with poor digestibility of dietary Zn. Diets with large amounts of soy protein are especially likely to need extra Zn fortification for farm animals. In human diets, meat is an important source of Zn, and many people with suspected Zn deficiency consume very little meat. No relationship has been found between the level of available Zn in soils where food crops have been produced and the occurrence of Zn deficiency in people.

Research indicates that Zn fertilization of food and feed crops may be potentially very useful in improving plants as sources of dietary Zn. The most effective use of this practice will require an extensive system of analyzing crops to determine the levels of Zn present. Until such a system is established, the use of soluble Zn salts will be the most practical method of insuring adequate Zn in human and animal diets. Zinc is not highly toxic to animals and a substantial margin of safety exists in using dietary Zn supplements.

TRACING ESSENTIAL ELEMENTS THROUGH THE FOOD CHAIN

How do essential elements move from the soil to the edible parts of plants? What are the chemical forms of these elements in plants? What is the digestibility of the different forms? How are these

FN-4010

The first step in tracing the movement of an element into plants is usually to grow the plant in a soil or culture solution containing a radioactive isotope of the element. Here, radioactive chromium is being added to a culture solution for growing wheat.



FN-4011

The plants grown with radioisotopes are harvested, homogenized or cooked, and fed to laboratory rats. The rats are placed in special cages so that scientists can determine how much of the isotope is eaten and how much is excreted in the feces and the urine.



metabolized in animals? Scientists at the U.S. Plant, Soil and Nutrition Laboratory at Cornell University are trying to answer these questions, using some of the techniques shown here.



PN-4012

At various times after the rat has eaten the radioactive food plant, the amount of the radioisotope remaining in the rat is measured by placing it in a device called a whole body counter. The heavy shielding is to prevent interference from cosmic rays of other stray radiation.



PN-4013

Specific organic compounds in plant and animal tissues are isolated and identified to help understand some of the chemical processes involved in digestion. The dark spots in the tubes in the vessels at the lower right are metal-binding proteins from rat intestine. They have been isolated by disk gel electrophoresis.

Other Elements That May Be Essential

In addition to the elements already discussed, several others have had some beneficial effects on laboratory animals. These include nickel (Ni), strontium (Sr), tin (Sn), and vanadium (V). Probably some of these, or perhaps others, will become definitely established as required elements for plants or animals when more research is done. Like most of the previous elements, Ni, Sr, Sn, and V can be toxic to animals if present in the diet in excessive amounts and in certain chemical combinations.

There is no evidence of any relationship between the levels of these elements in soils or plants and the nutrition of man and animals. The concentration of these elements in food and feed crops is normally very low. Research on the movement of these and other elements in the chain from soils to plants to animals is underway, and as this research progresses, findings that can be used to improve human or animal health may be obtained.

Some Potentially Toxic Elements

Some elements especially noted for their detrimental effects on plants or animals occur in certain soils, or they may be added to soils in fumes from polluted air or in compounds used to control insects or weeds. Concern over the movement of toxic elements into food crops is centered primarily on arsenic, cadmium, lead, and mercury. Other elements may be added to these with the continuation of research on environmental effects on human health.

Arsenic (As) has been added to farm soils in insecticide residues, and some As compounds are used to control weeds or to defoliate crops in order to facilitate harvest. Different chemical forms of As vary in their toxicity, with the arsenites among the more toxic. The accumulation of As in soils may sharply decrease growth of crops, and some fields formerly used as orchards show a very spotty pattern of crop growth, because As from spray residues has accumulated in circles around the site of each former tree.

The stunted crops grown on these As-polluted soils contain relatively little As in their foliage or seeds. Arsenic pollution of soils is therefore a hazard to the productivity of fields where As residues accumulate, but it is not a hazard to the human or animal that eats plants grown on these fields. Animals may be poisoned if allowed to eat the foliage of recently sprayed plants. Soil tests are very useful in predicting how much As can be applied to soils without decreasing crop growth. Use of arsenical herbicides or defoliants should be monitored with these tests to prevent overuse.

Cadmium (Cd) is used in metal plating and other industrial processes and may be added to soils in fumes from these industries, in smoke from coal and other fossil fuels, or in fumes from processing of

Cd ores. Sewage sludge from cities with industries using Cd may contain relatively high levels of Cd unless precautions are taken to prevent discharge of Cd wastes into the sewer system. No soils have been found, in the absence of Cd pollution, with natural Cd in sufficient amounts to cause toxic concentrations in crops growing on them.

In the soil Cd acts similarly to zinc (Zn). Where the level of Cd in the soil is high and the level of available Zn is very low, food and feed crops may accumulate concentrations of Cd that could be injurious to people or animals that eat these crops. The concentrations of dietary Cd that may injure people and animals are not known with any degree of certainty.

There are several promising methods of minimizing the detrimental effects of any Cd that may be added to the soil or to other stages of the food chain. Use of Zn fertilizers to increase the level of available Zn in the soil will sometimes reduce the amount of Cd taken up by plants. The judicious addition of certain compounds of Zn and selenium to the diet may help to counteract the toxic effects of dietary Cd. The exact situations in which these measures may be effective have not been clearly defined, and until they are known, measures to reduce Cd discharge into air and water are the most practical approaches to this problem.

Lead (Pb) is discharged into the air from auto exhaust fumes and other sources and was at one time a component of sprays used to control insects and plant diseases. When airborne Pb is incorporated into soil, nearly all the Pb is converted to forms that are not available to plants. Any Pb taken up by plant roots tends to stay in the root instead of moving to the top of the plant. Only on very heavily polluted soils will significant amounts of Pb move from the soil through the roots to the tops of plants. So the hazard of Pb pollution of food and feed crops is primarily one of airborne Pb being deposited on leaves and other edible portions of the plant by direct fallout.

Animals and people may inhale airborne lead. It may get into food and water from contact with lead pipes, utensils, and certain types of glazed pottery. The ability of soils to convert Pb to inert forms will minimize future hazard of the Pb from fallout.

Mercury (Hg) has been discharged into air and water from industrial operations and has been used in herbicides and fungicide seed treatments. Inorganic Hg is not highly toxic, and plants grown on soils containing it have very low concentrations of this element. Under certain conditions, especially in poorly aerated sediment on the bottom of streams and lakes, inorganic Hg may be converted to the highly toxic methyl mercury. Some of the Hg compounds used as seed treatments are readily converted to methyl mercury. Tragic cases of methyl mercury poisoning have occurred where grains have been treated with Hg compounds and then eaten by people or animals instead of being

planted. Methyl mercury poisoning has also occurred where Hg from industrial plants has been discharged into water and converted to methyl mercury and then accumulated in fish or shellfish.

Grain crops produced from Hg-treated seed and food crops produced on soils treated with Hg herbicides have not been found to contain harmful concentrations of this element. Even so, disposal of Hg compounds by spreading them on soil cannot be suggested. Under some laboratory conditions, adding selenium to diets containing methyl mercury has provided substantial protection against methyl mercury poisoning of laboratory animals. Conditions where this protection by selenium may be effective for people have not been established. The control of Hg uses and its discharge from industrial operations is of primary importance in preventing future hazards of Hg poisoning.

Special Precautions on Pesticides

Pesticides used improperly can be injurious to man, animals, and plants. Follow the directions and heed all precautions on the labels.

Store pesticides in original containers under lock and key—out of the reach of children and animals—and away from food and feed.

Apply pesticides so that they do not endanger humans, livestock, crops, beneficial insects, fish, and wildlife. Do not apply pesticides when there is danger of drift, when honey bees or other pollinating insects are visiting plants, or in ways that may contaminate water or leave illegal residues.

Avoid prolonged inhalation of pesticide sprays or dusts; wear protective clothing and equipment if specified on the container.

If your hands become contaminated with a pesticide, do not eat or drink until you have washed. In case a pesticide is swallowed or gets in the eyes, follow the first aid treatment given on the label, and get prompt medical attention. If a pesticide is spilled on your skin or clothing, remove clothing immediately and wash skin thoroughly.

Do not clean spray equipment or dump excess spray material near ponds, streams, or wells. Because it is difficult to remove all traces of herbicides from equipment, do not use the same equipment for insecticides or fungicides that you use for herbicides.

Dispose of empty pesticide containers promptly. Have them buried at a sanitary land-fill dump, or crush and bury them in a level, isolated place.

NOTE.—Some States have restrictions on the use of certain pesticides. Check your State and local regulations. Also, because registrations of pesticides are under constant review by the Federal Environmental Protection Agency, consult your county agricultural agent or State Extension specialist to be sure the intended use is still registered.

Nitrogen in Soil and Protein in Crops

All proteins contain nitrogen (N) and plants must obtain N in order to form protein. Increased crop yields and a higher concentration of protein in the crop frequently result when N fertilizers or N-bearing manures are applied to N-deficient soils. Farmers are using over 20

million tons of N fertilizers each year. The world consumption of N has more than tripled since 1960, and yet a shortage of protein in human diets in developing countries is still a pressing problem. The use of N fertilizer will not, by itself, correct this problem. To understand the relationship between N in soils and the problems of protein in nutrition, it is necessary to consider the nature of proteins and how proteins are formed in plants and utilized by people and animals.

Proteins are long, chainlike molecules built up by the linking together of 20 different organic compounds called amino acids. Hundreds of amino acid links may be present in one protein molecule. The chainlike protein molecules are usually coiled and cross-linked. A single cell may contain thousands of different kinds of protein chains.

Most of the N from the soil is taken into the plant as inorganic ammonium and nitrate ions, which sometimes are formed from the breakdown of soil organic matter, crop residues, or manures; at other times they are added to the soil as N fertilizers. Special groups of microorganisms can take inert nitrogen gas from the air and convert it to forms available to plants. In the legumes, such as clover or beans, these nitrogen-fixing bacteria live in nodules on the plant roots.

Regardless of the form in which N enters a plant, it is largely converted to ammonia and then combined with carbon, hydrogen, sulfur, and oxygen to form many different amino acids. The synthesis of amino acids is a complex, many-step process, and it follows a different pathway in the formation of each different amino acid. The rate at which amino acid synthesis proceeds is affected by the plant's nutritional status with respect to all the required elements and by the supply of metabolic energy needed to drive the synthetic processes. These processes operate under the control of the genetic inheritance of the plant. Inherited instructions provide for different rates and pathways of synthesis of amino acids in different plant species.

In the plant these amino acids form a "pool" of building blocks to be linked together to make protein. In most plants 75 percent or more of the total nitrogen is present as protein-bound amino acids. Anything to slow down the linking together of amino acids to form protein may lead to accumulation of free amino acids, nitrate, and other nonprotein nitrogen compounds.

Amino acids are combined into protein according to the genetic code contained in deoxyribonucleic acid. This code directs the formation of a template for protein synthesis made up of ribonucleic acid. This template controls the order in which each of the 20 amino acids is linked into the protein chains. Each kind of protein contains a different sequence of the 20 amino acids. The order in which the different amino acids occur along the completed chain determines the characteristics of the protein and its role in the plant's metabolism. Many of the proteins are enzymes that conduct the life processes essential for plant growth.

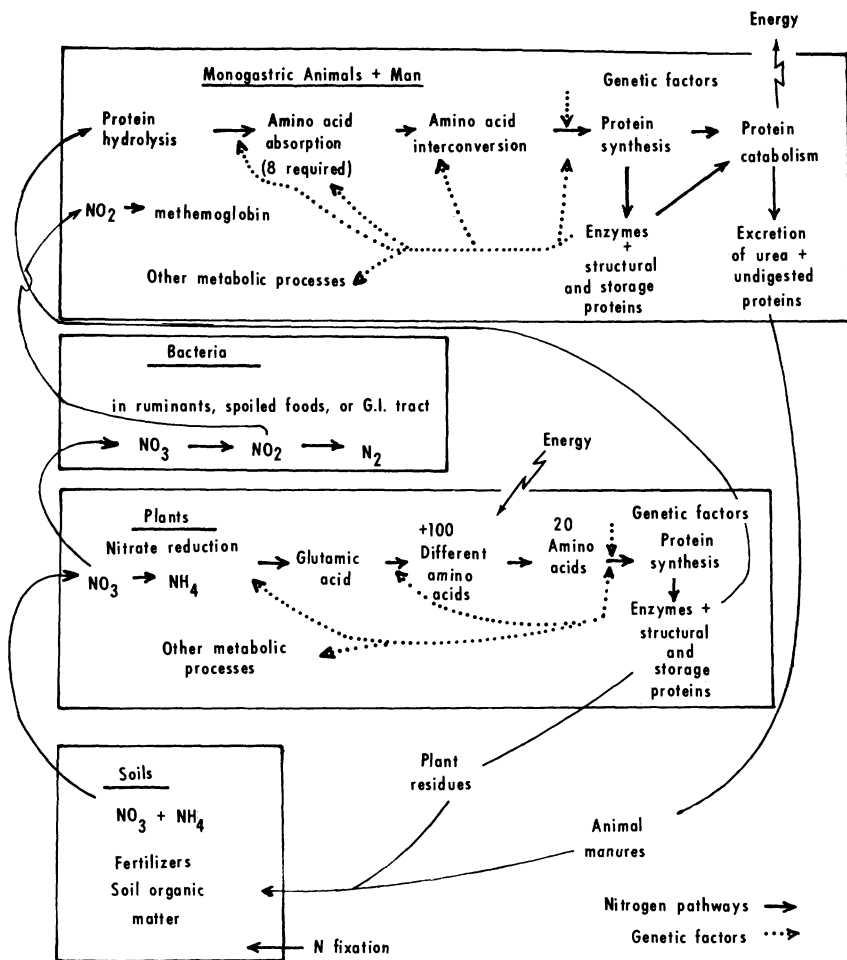


FIGURE 8.—Some of the nitrogen pathways in the food chain.

The frequency with which certain amino acids occur along the protein chains affects the nutritional quality of the protein for the person or animal that eats the plant, because people and animals require specific amino acids. An early step in the digestive process is the cleavage of the protein chains in the food into the individual amino acids from which they were made up. Of the 20 amino acids linked together in protein molecules, 8 or 9 are required in different amounts in the diet of people and animals. If the required amino acids are present in the diet, the animal can form the others, or the so-called nonessential amino acids. Then the amino acids are again linked together, but this time under the direction of the genetic inheritance of the animal to form the proteins of the animal body, or of milk, or eggs.

Diets deficient in specific amino acids can be made adequate by supplying these in the free form. They do not need to be combined into protein. So the protein requirement in human and animal diets is really a combination of amino acid requirements.

Plant proteins are often deficient in the essential amino acids—lysine, methionine, and tryptophan. Proteins from foods of animal origin, such as meat, milk, and eggs, often are of higher nutritional quality, that is, they contain the essential amino acids in better ratios than do plant proteins, especially seed proteins. Protein malnutrition, especially in young children, has been common in countries where plant products are primary sources of dietary protein. However, human diets containing desirable amounts and ratios of the essential amino acids can be prepared from plant sources by blending together different plant proteins, selected so that each of the essential amino acids is present in one or more. With some plants, progress is very encouraging in breeding such varieties as “high lysine corn,” which has improved levels of essential amino acids.

Ruminants seem at first to be an exception to the rule that animals require specific amino acids. However, micro-organisms in the rumen synthesize amino acids needed by these animals from the N compounds in the diet. The amino acids thus synthesized are combined into the proteins of the micro-organisms, and these proteins are then broken down into the amino acids required by the animal as they move farther along the digestive tract. Simple N compounds, such as urea, can be converted into amino acids and protein in the rumen, and inorganic sulfur compounds are converted into sulfur-bearing amino acids. The ruminant performs the special function in the food chain of converting forages and low quality proteins that are unsuited for direct use by people into the proteins of meat and milk, which are excellent human food.

In essence then, an adequate level of soil fertility gives the crop a chance to form protein. This fertility level includes all the nutrients required by the plant, not just the nitrogen and sulfur that are present in the proteins themselves. Every element needed for plant growth can be said to be required for protein synthesis. Given a chance to form protein, the plant will form the kinds of proteins dictated by its genetic inheritance. Crops growing on fertile soils produce more protein per acre because they produce high yields, and the concentration of protein in the crop is increased. But even the total protein concentration is subject to genetic control. No level of fertility will produce rice that contains as much protein as soybeans. The nutritional quality of the protein, that is, the ratio of the essential amino acids to each other and to the nonessential amino acids, is controlled by the genetics of the species and the variety of the crop.

The Nitrate Problem

Whenever nitrate moves from the soil into the plant more rapidly than it is metabolized to form amino acids and protein, the plant may accumulate high concentrations of nitrate, sometimes 5 percent or more of its dry weight. Although nitrate itself is not very toxic to animals, high concentrations of nitrate in food and feed crops are generally undesirable, because under certain conditions in the digestive tract or in stored foods the nitrate may be converted to nitrites. Nitrites are toxic to animals, because once absorbed into the blood they react with hemoglobin in a way that interferes with the transport of oxygen in the bloodstream. When forages containing high levels of nitrate are put in silos, oxides of nitrogen (N) may be given off as gases during the silage fermentation process. These gaseous oxides of N may be lethal if inhaled by people working around the silo.

Accumulation of high levels of nitrate in plants is usually the result of high levels of nitrate in the soil, plus the impact of some environmental factor, such as drought or cloudy weather, which slows plant growth or protein synthesis. The relative importance of soil nitrate levels and environmental factors varies under different conditions. Unusually high levels of nitrate in the soil may cause high levels of nitrate in plants, even when environmental conditions are generally favorable to plant growth.

High levels of nitrate in soils may result from excessive use of N fertilizers, excessive use of readily decomposed composts or manures, accumulation of nitrate from organic matter during fallow or drought periods, or the rapid breakdown of organic matter and legume green-manure crops. However, plants containing high levels of nitrate often have been found growing on soils that have not received any fertilizer, manure, or compost.

Different plants show markedly different tendencies to accumulate nitrate. Annual grasses, cereals cut at the hay stage, some of the leafy vegetables, and some annual weeds are most likely to contain high levels of nitrate. High concentrations of nitrate occur much less frequently in legumes and perennial grasses, but even these species are not completely free from the problem. Within any one plant the nitrate level in the seeds or grain is nearly always lower than in the leaves. High levels of nitrate have not been found in the grains used as food and feed crops.

Forage crops high in nitrate are especially dangerous to such ruminants as cattle and sheep. The rumen of these animals provides an environment conducive to reducing nitrate to the toxic nitrite. Losses of cattle and sheep due to nitrite poisoning have been a serious problem in livestock production for many years, especially during seasons when cloudy weather or drought interrupts plant growth.

In single-stomached animals and man, nitrate in the food is rarely

reduced to toxic concentrations of nitrite unless infection has led to formation of abnormal organisms in the gastrointestinal tract. In the United States no authenticated cases of human poisoning have been traced to high levels of nitrate in food crops. When foods high in nitrate are attacked by bacteria during improper storage, the nitrate may be converted to nitrite. Cases of nitrite poisoning have been reported in European infants due to consumption of high nitrate vegetable baby foods that were improperly stored.

Nitrites may also react with certain N compounds resulting from the breakdown of amino acids to form nitrosamines. Some of the nitrosamines are carcinogens. Nitrosamines have been found in meats cured by using sodium nitrite as a preserving and coloring agent. Nitrosamines are apparently much less common in foods of plant origin, even from high nitrate plants. Ascorbic acid or vitamin C in foods may destroy nitrites and prevent the formation of nitrosamines. Until the relationship, if any, between nitrate in food plants and nitrosamine formation is better understood, precautions to reduce nitrate or nitrite levels in food plants are desirable.

Even though nitrate in food crops may not present a major hazard to people, nitrate in forage crops is a hazard to cattle and sheep, and when this occurs it can cause large losses. Furthermore, nitrate in plants at harvesttime represents wasted N in the food chain. Nitrate accumulations in soil may be leached into ground waters and lead to excessive growths of algae in lakes and streams and to high nitrate levels in domestic water supplies. Excessive accumulation of nitrate, either in plants or in soils, is undesirable from the standpoint of potential toxicity and water pollution and wasteful in the N economy of the ecosystem.

Attempts to avoid excessive levels of nitrate in soils and plants must be based on the fact that a massive flow of nitrate from soils to the roots of feed and food crops is essential to food production. In the United States the food and feed crops take up at least 3 million tons of N from the soil each year. Most of this N enters the plant in the form of nitrate.

A major step in an attempt to control nitrate accumulation in plants is to develop systems of soil management, including the use of fertilizers, manures, and crop residues, which provide ample but not excessive supplies of available soil nitrate for food and feed crops. The level of nitrate in the soil must be timed to fit varying demands of plants at different stages of growth. The supply of nitrate from fertilizers, manures, and composts must be adjusted to the expected release of N from soil organic matter. Excessive use of N fertilizers just to insure against N deficiency should be avoided, but judicious use of N fertilizers is essential to food production.

Even when soil-management practices are closely adjusted to the N

requirement of plants, crops containing high levels of nitrate may be produced because of unexpected weather conditions. When conditions conducive to nitrate accumulation have occurred, stockmen should have their feed crops tested for nitrate and then dilute feeds high in nitrate with low nitrate feeds. Silos containing crops suspected to be high in nitrate should be thoroughly ventilated before anyone enters.

The nitrate concentration of food crops can be monitored as these crops are processed for canning, freezing, or distribution. Crops with high nitrate concentrations should not be used for baby foods. Home gardeners who suspect high nitrate levels in their vegetables should discard the water used for cooking these vegetables, since most of the nitrate in plants is soluble and will be removed in this way. Where potential nitrate-accumulating vegetables, such as spinach and beets, are canned or frozen, they should be used soon after the containers are opened to avoid nitrite formation during nonsterile storage.

Soil Fertility and Vitamins in Plants

In order for people to remain healthy, their diet must contain at least 14 vitamins. Vitamins are organic compounds, which are synthesized within plants or within animals. The amounts of different vitamins that people need each day are very small, and vitamin requirements are often specified in terms of thousandths or even millionths of a gram per day. But in spite of the fact that vitamins are required in very small amounts, vitamin deficiencies have been responsible for critical nutritional diseases, such as rickets, scurvy, poor sight, and pellagra.

Just prior to World War II there was substantial concern among scientists that differences in the fertility of various soils or soil depletion might adversely affect the levels of vitamins in food crops. This concern prompted a series of studies at the U.S. Plant, Soil and Nutrition Laboratory of factors affecting the vitamin content of plants. Experiments were conducted on the vitamin content of plants as affected by different soils, different geographic locations, different plant varieties, levels of minerals in solution cultures, organic and inorganic fertilizers, and other variables. The food crops studied included tomatoes, carrots, turnip greens, wheat, potatoes, and some others. Most of these studies were concerned with carotene or provitamin A and vitamin C or ascorbic acid in plants, since plants are important dietary sources of these vitamins. However, niacin, thiamin, and riboflavin were included in some of these studies.

The results showed that the concentration of carotene was somewhat related to the mineral nutrition of the plant or the fertility of the soil on which it grew. Whenever a mineral deficiency was so severe as to discolor the plant, such as a yellowing of normally green leaves, the con-

centration of carotene in the plant was reduced. Thus, treatment of the soil with iron to correct severe iron deficiency or with boron to correct severe boron deficiency resulted in an improved level of carotene in the plant. Where the plants grew normally without loss of green color due to mineral deficiencies, the carotene content was dependent on the species and variety of the plant. Since mineral deficiencies that result in severe plant discoloration usually lead to very low crop yields or even to complete crop failure, there is very little chance that plants of abnormally low carotene content would ever be commonly used in human diets.

The level of vitamin C in plants was found to depend heavily on the amount of sunlight striking the plant. Tomatoes grown in a sunny climate contained more vitamin C than those grown in cloudy areas, regardless of the kind of soil used. If a fertilizer treatment produced very large, bushy tomato vines that shaded the ripening fruits, these shaded fruits would have less vitamin C than those growing on smaller, less leafy vines. All the studies using different food plants indicated important effects of sunlight intensity on the vitamin C in the plant.

The effect of plant species or variety appeared to be the dominant factor controlling the level of the other vitamins in plants. Most of the thiamin in wheat grain is present in the seedcoat. When the wheat is milled into flour, the thiamin will be removed in the bran.

Vitamin D can be formed by the action of sunlight on human skin. People who are normally outside in sunny regions for long periods need less of this vitamin in their diets than those who are normally indoors most of the time.

Vitamin B₁₂ is not formed in food plants, but plants may serve to transfer the mineral cobalt, an essential atom in the B₁₂ molecule, from the soil to ruminant animals, where vitamin B₁₂ is synthesized by bacteria in the rumen. The vitamin B₁₂ formed in the rumen of cattle, sheep, and goats moves on into human diets in the meat, milk, and cheese derived from these animals.

The vitamin nutrition of people is often dependent on food selection and on losses of vitamins during processing and storage of foods. Plants that grow normally and produce satisfactory yields can be expected to contain normal levels of whatever vitamins are characteristic of that species and variety. Plant breeders have developed new varieties of vegetables that are richer in certain vitamins than some of the older varieties. But no one plant contains adequate levels of all the vitamins needed by people, regardless of the variety planted or the place where it grows. Human nutritional diseases due to vitamin deficiencies have been critical for many years, but they have never been known to be caused by any deficiency in the soil where the food crops were grown.

Soil Depletion and Nutritional Quality of Plants

Many of the food crops produced in the United States are grown on soils that have been used for farming for a long time. Some people have expressed concern that these soils have become so depleted of nutrients during years of farming that the nutritional quality of the food crops produced on them has declined. Some of this concern stems from the belief that the common types of fertilizers used meet only the crop requirements for the major elements, such as nitrogen, phosphorus, and potassium, and permit soil reserves of the trace elements to decline to levels that may jeopardize the nutritional quality of crops. At the same time other people have maintained, on the basis of improved public health statistics, that the nutritional quality of today's crops is improved over that of crops of early periods. This controversy must be examined in terms of specific nutrients and specific crop-production and soil-management systems.

The use of soils for crop production for many years does not automatically cause soil depletion. Many soils have been improved in their nutrient supply through use of modern farming practices. When some of the sandy soils of the U.S. eastern seaboard were cultivated by the colonists, the first crops suffered from many nutrient deficiencies, and westward movement to find better soils was taking place before the Revolution. Some of these fields have since been built up from continued use of fertilizers, lime, animal manure, and green-manure crops to where they are among the most productive vegetable crop soils of the world. Similar instances of soil improvement during long periods of agricultural use are found in western Europe.

Probably many soils of the United States now contain more abundant reserves of some plant nutrients than they did when they were first cultivated, and yet the supply of other nutrients has been partially depleted from these same soils. The total amount of nitrogen in the black soils of the Midwestern United States has undoubtedly declined since these soils were first cultivated. Most of this decline appears to have taken place during the first 50 years after settlement, and some measurements of long-term trends of the nitrogen content in these soils indicate that it is now stabilizing at levels somewhat below those when they were newly plowed from the native prairie grasses. But many of the farmers using these soils have regularly applied phosphorus fertilizers and limed these soils so that crops like alfalfa could be grown. So the same soils that have been partially depleted of nitrogen may contain more phosphorus or calcium than they did in 1900.

Whether or not depleting some elements and increasing others will affect the nutritional quality of the crops produced will depend on which of the elements, if any, are limiting the nutritional quality of the crop for the human or animal consumer. This question can only

be analyzed with respect to each nutrient that may have been changed and with reference to preceding statements in this bulletin about the individual nutrients.

This type of individual consideration of the different elements and compounds required by humans and animals indicates that the concentrations of most of the vitamins and the concentration and nutritional value of the protein in food plants are controlled primarily by the nature of the plant itself, or perhaps by the amount of sunlight it gets. These are not likely to be greatly affected by changes in the nutrient supply in the soil. The average concentration of phosphorus in food crops grown on commercial farms is probably as high as or higher than that in similar crops grown 50 years ago because phosphorus fertilizers have been extensively used. The concentration of iron and manganese in plants is controlled most often by factors that affect the ability of the plant to utilize these elements and seldom by the total amount of the element in the soil. The sodium, chlorine, and iodine required by people have been supplied by direct supplementation of diets, and changes in the levels of these elements in soil or in food crops would have no effect on human nutrition.

Of all the mineral elements required by people and animals, downward trends in the concentration of zinc, magnesium, and possibly sulfur in food and feed crops would appear to be more likely than for any of the others. Even with these elements any evidence of a decline must rest on circumstantial evidence, such as increasing reports of magnesium deficiency in cattle or need for zinc or sulfur fertilizers to obtain optimum crop yields. There is no evidence that a decline, if there has really been a decline, in the concentration of zinc, magnesium, or sulfur in food crops has had any effect on the nutritional status of people. The nutritional status of people with regard to these elements is strongly dependent on food selection practices, dietary habits, and utilization of these elements from the diet.

There are very few recorded measurements of the concentrations of essential minerals characteristic of the food crops 50 years ago. Chemical procedures for measuring the concentration of some of the essential trace elements were not developed at that time. Therefore very little direct evidence exists of changes that may have taken place in the concentration of most of the essential nutrients in food crops.

Some of the most dramatic cases in humans or animals of nutritional deficiencies that trace to a mineral deficiency in certain soils date back a long time and are due to naturally occurring deficiencies rather than those due to soil depletion. In the writings of Shakespeare there is reference to a high incidence of goiter in mountainous regions now known to be low in iodine. The cattle of the early colonists of the Sacco Valley of New Hampshire suffered from a "wasting disease," which was attributed to a curse placed on the valley by the Indian Chief Chocorua. The "curse of Chocorua" is now known to be due to cobalt

deficiency. When the Columbia Basin of the Northwestern United States was first used for irrigation agriculture, zinc deficiency was so severe that corn and bean crops failed on many farms. These naturally occurring deficiencies and many similar ones have since been corrected by such measures as use of iodized salt, trace element fertilizers, and mineral supplementation of animal diets.

In considering the effects of man's use of soils for agriculture, it is necessary to distinguish between depletion of the soil's supply of the essential elements for plants and animals and deterioration of the soil due to washing or blowing away of surface soil to expose hard or rocky subsoil material. Depletion of the soil's supply of essential nutrients has generally been recognized by agricultural research workers and has usually been corrected by proper use of fertilizers before there is any decline in nutritional quality for man or animals of the crops produced. It is often much more difficult to correct or reclaim areas that have been damaged by excessive erosion or soil blowing. Some of the historical records of failure of settlements in certain parts of the world can be attributed to a failure of crop production from destruction of the soil by erosion or to the "salting out" of irrigated lands. There are no records where failure of settlements can be attributed to crops of poor nutritional quality resulting from depletion of the soil's supply of essential elements.

Organic and Inorganic Fertilizers in Relation to Nutritional Quality of Crops

Many of the better farming soils of the United States contain a relatively high level of organic matter. They are usually easy to till, the rain soaks in rapidly, plants growing on them withstand droughts better, and they have many other desirable properties. Since organic matter has so many desirable effects on soil properties, some people have speculated that adding organic matter to soils might result in crops of improved nutritional quality, and they have extended this to assert that the use of inorganic or chemical fertilizers might have undesirable effects on the nutritional quality of crops. Sometimes the concern over the effects of persistent insecticides or of food additives has led to condemning the use of all chemicals, including chemical fertilizers, and a belief that return to some natural system of food production might provide a cure for a wide variety of nutritional problems.

When experiments have been conducted to compare the levels of different essential nutrients in crops grown with organic fertilizers against those grown with comparable amounts of nutrients supplied as inorganic materials, the differences measured have been small, with the advantages in favor of the inorganic as often as of the organic forms. There have been a few experiments in which the plants have been fed to test animals, and here again the small differences noted in

animal growth have not consistently favored either the organic or inorganic sources of the nutrients.

These results are expected on the basis that the function of plants in the food chain is, as pointed out previously in this bulletin, to convert inorganic compounds to organic compounds. If organic materials containing essential elements are incorporated into soil, the micro-organisms in the soil break down the organic matter into inorganic forms. Inorganic ions of the essential nutrients are then taken up by plant roots and elaborated into new organic materials within the plant. In the plant, and in the body of the human or animal that eats the plant, these essential nutrient elements have the same effect, regardless of whether they were added to the soil in the form of organic fertilizers or as inorganic chemical fertilizers. There is no laboratory test or animal feeding trial that will distinguish between crops grown with inorganic or with organic fertilizers.

The principal benefit from adding such organic materials as farmyard manure, composts, crop residues, sewage sludge, and peat is that these materials nearly always improve the physical properties of the soil. These physical properties include the soil's ability to hold water, its crumb structure, its resistance to erosion by water, and its resistance to crusting from beating of the rain. Organic materials may be especially valuable for these purposes to the gardener who is establishing a lawn and garden on subsoil exposed by grading or from excavation of basements.

Some kinds of organic materials can be very useful because they provide a steady, slow release of the plant nutrients they contain. With this slow release of the plant nutrients, due to the slow decomposition of the organic material to form inorganic ions of the nutrients, plants have a steady supply of nutrients throughout the growing season and less nutrients are lost to the leaching of heavy rains. Some of the inorganic fertilizers are now compounded so as to provide a slow release of their nutrients and can be effective in providing a steady supply of nutrients.

The timing of the release of nitrogen from organic materials depends on the ratio of nitrogen to carbon or of nitrogen to energy-yielding material in the organic matter. Organic materials, such as cornstalks, straw, and leaves, are usually low in nitrogen. When these materials are added to soil, the micro-organisms will use all the nitrogen contained in them and any nitrates and ammonia already in the soil for their own metabolism during the breakdown of the carbon compounds in the organic matter. Crop plants growing on soil to which low nitrogen organic materials have recently been added will suffer from nitrogen deficiency. But as the organic matter decomposes, all but the most resistant carbon compounds are broken down, and the micro-organisms themselves die and decompose, releasing the nitro-

gen from their cells for use by crop plants. The supply of available nitrogen in the soil is then increased.

Home gardeners can prevent the temporary tieup of available nitrogen by composting low nitrogen materials until most of the carbon compounds are broken down. Many home gardeners add chemical nitrogen fertilizers to their compost heaps to speed up decomposition and yield a compost with a favorable nitrogen to carbon ratio. On commercial farms where cornstalks or straw is plowed under just prior to planting the next crop, nitrogen fertilizers must be added at a rate to meet the needs of both the new crop and the micro-organisms that are decomposing the previous crop residue. When an organic material relatively high in nitrogen, such as well-rotted farmyard manure or a green-manure crop of alfalfa or clover, is plowed down, release of inorganic nitrogen proceeds very soon, and this flow of nitrogen from organic to inorganic forms may substantially meet the nitrogen needs of the next crop.

Often the addition of organic materials can render the soil reserves of such nutrient elements as iron, zinc, or manganese more soluble and available to plants. Iron deficiency of plants growing on some alkaline soils can be corrected by plowing under heavy applications of barnyard manure. This iron deficiency can also be corrected by using inorganic iron fertilizers or sprays or by adding sulfur to make the soil more acid. But on many livestock farms the use of manure to correct this iron deficiency is easier and more practical.

Organic matter must be used with care in making soil reserves of certain trace elements available to plants. When soils with alkaline subsoils are graded to permit more uniform distribution of irrigation water, the spots where the surface soil is cut away are frequently very deficient in zinc. This deficiency can often be corrected by applying farmyard manure. But the long continued heavy applications of manure may ultimately cause more zinc deficiency. "Corral disease" is a term used to describe zinc deficiency in citrus trees growing on sites that have received heavy applications of manure. Some organic materials may tend to make soil copper less available to plants. Severe deficiency of copper resulting in low crop yields and copper deficiencies in grazing animals are common problems on highly organic soils, such as peats and mucks.

An important reason for adding organic materials to agricultural and garden soils is that this practice can be used to recycle the organic material without damaging the environment. This is especially useful with sludges produced in municipal sewage-treatment plants. If these organic sludges are dumped into streams, water pollution and other environmental damage result, but if they are spread on land they can be beneficially effective. Sludge from municipal sewage-treatment plants can be especially useful in revegetating new roadbanks or surface-mined areas.

A sewage-treatment process to prevent dispersal of disease organisms is essential, and raw sewage should not be used. The sewage sludge from treatment plants serving industrialized areas may contain concentrations of such toxic heavy metals as cadmium, which will limit the amount of sludge that can be used with safety. Many cities have sanitary district offices that can inform potential users of sewage sludge about precautions necessary for safe use of material from specific treatment plants.

On home gardens the organic materials are less likely to be used excessively simply because the sheer bulk of material to be handled discourages overuse, whereas the home gardener may easily apply excessive amounts of concentrated inorganic fertilizers. Problems from excessive use of organic materials are generally confined to locations near large feedlots or large poultry houses, where costs of transporting the manure and poultry-house litter tend to encourage heavy applications on the closest fields. Nitrate toxicity and grass tetany in cattle have been serious problems where pastures located close to large broiler houses have received excessive applications of broiler-house litter.

So the application of organic matter to farm and garden soils is a generally beneficial practice even though it cannot be considered a panacea for the problems of nutritional quality of plants. Some of these nutritional problems can only be corrected by inorganic fertilizers or mineral food and feed supplements. Iodine deficiency in people cannot be corrected by organic or so-called natural fertilizer practices unless organics from seaweed or marine fish byproducts are transported to the iodine-deficient interiors of the continents. The cobalt deficiency that plagued the cattle of colonists in New Hampshire did not respond to organic fertilization practices because the organic materials available to these colonists contained very little cobalt.

Systems for producing high yields of high quality food and feed crops often require proper use of both organic and inorganic or chemical fertilizers. Many of the commercial farms in the United States and Europe use both organic material and inorganic fertilizers. Where corn, wheat, barley, and soybeans are produced on commercial farms, nearly all the crop residues, such as cornstalks and straw, are returned to the soil. On most livestock farms the manure is regularly spread on the fields where the feed crops were grown. The leaf fall from commercial citrus and apple trees returns to the soils of the orchards.

The amounts of crop residue, such as cornstalks, that are returned to soils of commercial farms in the United States each year indicate that the so-called commercial farms are the biggest users of organics. A comparison of crops produced on commercial farms with those of "organic farmers" is frequently a comparison of two systems that both use organic materials.

The first step in modern procedures for manufacturing chemical nitrogen fertilizer is the combining of nitrogen from the air with hydrogen from natural gas or oil under high temperatures and pressures to form ammonia. Thus, the production of chemical nitrogen fertilizers competes with other demands for fossil fuel. Calculations of the energy required to spread organic materials, such as farmyard manure, on cropland indicate that efficient spreading systems require less energy in terms of tractor power and machinery manufacture than would be required in the manufacture and distribution of an equivalent amount of chemical nitrogen fertilizers. Where efficient systems of loading, transporting, and spreading can be developed, the use of animal manures and sewage sludges may provide a valuable method of conserving fossil fuels.

Other measurements indicate that when a legume crop, such as alfalfa, is grown for 1 year and plowed under, about 100 pounds or more of nitrogen may be added per acre through the fixation of nitrogen from the air by the micro-organisms in the nodules on the legume roots. In warmer areas the winter cover crops of legumes, such as vetch or crimson clover, may be used to fix nitrogen for the next summer's crop. Normally the amount of nitrogen accumulated by these winter cover crops is less than that accumulated by such crops as alfalfa and sweetclover. Any soil deficiencies of phosphorus, potassium, lime, and the trace elements will need to be corrected by inorganic fertilizers in order for the legumes to grow and fix nitrogen.

The food-production systems of the future will almost certainly include a combination of organic and inorganic fertilizers. The exact nature of this combination will vary for different farms and for different countries depending on their access to fossil fuels, their soils, their food-production requirements, and many other factors. Regardless of the combination of inorganic to organic fertilizers that may be used, food plants of adequate nutritional quality can be produced if existing knowledge of soil chemistry and plant and human nutrition is applied and if research programs on the nutritional quality of plants are maintained.

General Aspects of Fertilizer Use and Human Nutrition

The need to consider specific nutrients and diets has been stressed in evaluating the effects of soils and fertilizer on human nutrition. It is very difficult to draw any conclusions from broad general comparisons of fertilizer use with the available statistics on human nutrition and health in different countries. Such countries as the United States, the Netherlands, and Japan with high rates of fertilizer use per capita or per cropland acre have longer average life expectancy than do the countries where fertilizer rates have been very low. National averages

of infant mortality are lower in the countries that use large amounts of fertilizer than in the countries that use very little. But these comparisons alone do not prove that fertilizer use increases longevity or decreases infant mortality.

The countries with high rates of fertilizer use per capita or per cropland acre differ in many ways from the countries with low rates. The fertilizer-using countries are generally developed countries of the Temperate Zone. They usually have public and private health services, modern standards of sanitation, and refrigerated food transport and marketing facilities. Most of the countries with low per-capita and per-acre fertilizer use are developing countries of tropical areas. They do not yet have the health services and the sanitary food-distribution systems of the developed countries. Any effects of national average practices of fertilizer use on national average health statistics are intertwined with effects of the entire complex of practices that make up modernization and economic development.

In the developed countries, fertilizer use is based on research conducted over many years. The results of this research are applied to specific kinds of soil and to individual farms by farm advisory services. In the United States many State agricultural experiment stations or extension services provide soil-testing laboratories. Farmers and gardeners can submit samples of their soils to these laboratories and receive advice on the fertilizer needs of their specific soil and crop combinations. Some States provide fertilizer advisory services based on leaf analysis of crop plants. Farmers who follow the recommendations of these advisory services will usually apply adequate levels of the essential nutrients to their crops without danger of overusing fertilizers or of creating imbalances in plant nutrition.

Soil survey maps enable farmers to compare their own soils with those of farms where fertilizer experiments and demonstrations have been conducted. Field experiments with fertilizers, soil- and plant-testing services, and soil survey maps are essential for effective use of fertilizers in food production.

Fertilizer use is just one of a set of practices, such as use of machinery and crop-protection chemicals, that are involved in food production. Farmers use fertilizers to obtain high crop yields and to grow new crops that cannot be grown on unfertilized soils. Thus, fertilizers contribute to the abundance and variety of the food supply. There is no evidence from public health statistics that this variety and abundance have been obtained at a sacrifice in the concentration of essential nutrients in the food crops produced. Fertilizers have been an essential part of a complex set of agricultural practices that have permitted people in the developed countries to exchange the nutritional problems of the hungry for the nutritional problems of the overfed.

Summary and Looking Ahead

The composition of food and feed crop plants, with respect to the levels of the nutrients essential for man and animals, is controlled by genetic, environmental, soil, and other factors. Sometimes the concentration of an essential mineral in the soil is so low that plants growing on it will not contain enough of that mineral to meet the dietary requirements of animals. Sometimes feed crop plants may contain such high concentrations of certain minerals that they are toxic to the animals that eat them. Direct effects of soil composition on human nutrition have been observed much less often than effects of soils on the nutrition of farm animals.

If these problems are considered on the basis of specific soils, specific essential nutrients or their combinations, and certain plant species used in specific diets, useful ways to insure optimum human and animal nutrition are usually evident. Some of the nutritional problems stemming from malfunctions of the food chain from soil to plant to man and animal have been recognized and solutions discovered through research conducted over long periods in many countries.

These research efforts will be needed even more in the future. There appear to be very promising opportunities to improve the nutritional quality of plants and to develop systems of soil management and crop production that will yield crops of even better nutritional quality than the best crops available today. Perhaps food crops will be developed with higher levels of readily digested zinc or magnesium. Increasing the amounts of nutritionally effective forms of chromium or some other newly recognized essential element in plants may be possible. Or the concentration of protein and the nutritional quality of this protein in important food crops may be improved through research.

If world populations continue to grow, with greater pressure on food supplies, it will become necessary to produce food and feed crops on some soils not now being used. In many instances, especially in the Tropics, these new cropland soils are likely to be deficient in several of the mineral elements required by man and animals. Effective research programs will be needed to insure that the crops produced on these soils contain adequate levels and the proper balance of essential nutrients.

The record of past accomplishment of research programs on these problems offers a substantial basis for the hope that future research work will be equally successful.